# THE INTENSIFYING HARMATTAN WINDS OF NORTHERN GHANA: IMPLICATIONS FOR AGRICULTURE

**A Thesis**

**Submitted to the Master's Study Program of Public Policy, Specialization in Climate Change at the Faculty of Social Sciences in partial fulfilment of the requirements for the degree of**

**Master of Public Policy (M.P.P.)**


by:

**Abdul-Razak Issifu Yidana**

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## ABSTRACT

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The Harmattan is a dry, dust-laden continental wind in West Africa which has its origin from the Sahara Desert. The season of Harmattan in Ghana takes place between November and March and traditionally, it has been considered a highly predictable seasonal event with very little analytical importance in the context of agricultural risk management. However, recent climatic and community reports in Northern Ghana suggest that the extent and duration of the Harmattan winds is rising with their longer persistence, higher dust concentrations, low humidity, and higher temperatures during dry periods. This creates an analytical research gap of the influence of the wind-driven, slow-onset climatic stressors on agricultural productivity in climate-sensitive regions. This paper discusses the growing intensity of the Harmattan winds in Northern Ghana and the impacts this has on agriculture, especially the Guinea and Sudan savannah regions where the system of rain-fed smallholder agriculture prevails. The study relies on the qualitative analysis based on climatic data provided by the Ghana Meteorological Agency (GMet), agricultural and institutional reports by national and international institutions, and peer-reviewed climate studies. Harmattan indicators are interpreted according to the time interval 2010- 2025. The existing reports show that there is obvious indication of increased duration of the Harmattan season, frequent temperature-humidity changes, and prolonged dust exposure. These atmospheric alterations are linked to soil moisture loss by winds, topsoil erosion during pre-planting, crop desiccation that does not depend on the rainfall failure, increasing irrigation expenses, and degradation of pastures. The analysis also reveals that the effects of the harmattan are analytically distinct, and these are not drought, but rather other physical processes and affect farming systems even when there are no extreme rainfall deficits. This paper will add to the literature on climate-agriculture by redefining the relationship between climatic risk and agriculture, instead of the narrow focus on rainfall-based models. The study also gives emphasis on the necessity of changing the mindset of the farmers, policy makers and early warning systems in Northern Ghana from rain-based to Harmattan related indicators including wind intensity, humidity suppression, dust exposure and evapotranspiration stress. It is necessary to incorporate them in agriculture planning and climate policy to increase the resilience of smallholder farmers in dryland areas, which are vulnerable to climate change.

Keywords: *Harmattan Winds; Northern Ghana; Dry-Season Atmospheric Dynamics; Evapotranspiration Stress; Wind-Driven Soil Erosion; Agricultural Vulnerability; Climate Risk Multiplier; Climate Adaptation Policy; Agricultural Resilience.*

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# CHAPTER I

# INTRODUCTION

The Harmattan is a dominant dry, dust-laden continental wind which has its origin from the Sahara Desert and blows towards the west coast of Africa during the winter and affects many West African countries, including Ghana (Lyngsie et al., 2013). High-pressure systems accumulated around these areas. It gives rise to a strong, dry north-easterly wind, which carries and moves great masses of fine dust and sand particles south-westwards across the Sahel and West Africa (*Figure 2*). This has an impact on atmospheric visibility, humidity, temperature regimes and surface conditions in large areas of West Africa (Knippertz & Todd, 2012; Lyngsie et al., 2013). The Harmattan continues to be a hallmark of dry-season climate variability in the sub-region in seasonal projections by the West African climate outlook forum (PRESAO) and other regional climate assessments by the World Meteorological Organization (WMO) (ACMAD, 2014).

Traditionally, the Harmattan has been considered in climate science mostly in the context of an atmospheric and air-quality process (Knippertz & Todd, 2012; Schulz et al., 2012). The Ghana Meteorological Agency (GMet) and other global meteorological agencies regularly check the conditions of the Harmattan using such indicators as decreased visibility, concentration of the particulate matter, deviation of temperatures, and humidity suppression. Nevertheless, in more encompassing climate risk and agricultural evaluation models, Harmattan has been much more conceptualized as a predictable seasonal background state as opposed to a dynamic climate stressor with changing features. This clearly highlights an important policy implication since agricultural risk management and climate adaptation policies prioritizes drought conditions and rainfall variability. This gives a limited attention to atmospheric stressors due to Harmattan winds.

Ghana Meteorological Agency (GMet) have documented longer and harsher spells of the Harmattan, which has reduced humidity, elevated levels of particulate matter, surging temperatures, seasonal change zones, and the increased conditions of dry-season across the regions (GMet, 2024). These patterns pose serious concerns of how the old systems of climatic regimes like the Harmattan are adapting to the overall climatic change processes and whether their effects are sufficiently reflected in the current analyses. This is alarming and brings concerns on how climate adaptation policies, agricultural resilience mechanisms and regional vulnerability assessments will effectively capture the impacts of the exacerbating Harmattan conditions.

### 1.1 Harmattan as an Emerging Agricultural Stressor

There is increasing evidence, based on National meteorological records and studies, which suggest that the Harmattan in some areas of West Africa can no longer be characterized as a consistent seasonal phenomenon. The new reports of GMet verify that the growing ability of heat in the dry season, the long spells of low relative humidity, and frequent occurrence of the particulate matter with even greater spatial extent have been recorded in Ghana. These stronger harmattan seasons, presents dust storms reaching even further south of Ghana than usual. This is in line with the IPCC AR6 findings of heightened compound occurrences such as heat, dryness, and circulation alterations in semi-arid regions (IPCC, 2022).

The rainfall-based agricultural impact assessment in West Africa is still very dominant. The indices of drought, deviations of precipitation, and seasonal quantity are still in the baseline of crop models and vulnerability analysis (IPCC, 2022; FAO, 2021). Consequently, wind-based mechanisms like increased evapotranspiration, mechanical damages on crops, erosion of topsoil, moisture loss during the dry season, among others, tend to be considered as secondary or incidental. Accordingly, adaptation mechanisms and agricultural planning initiatives in a high susceptible region such as Northern Ghana may underestimate the implications of atmospheric stressors to agricultural vulnerability.

Emerging empirical observations challenge this framing. In Northern Ghana and the larger Sudan Sahel region, crop drying due to scorching extreme heat and wind without precipitation shortages and planting delays due to Harmattan-related soil moisture loss and the increased irrigation demand of the dry season are progressively reported (Antwi-Agyei et al., 2018; Boansi David et al., 2023; Shirazu et al., 2022). These results indicate that atmospheric stress during the Harmattan does not act with the same mechanism with drought, and it should be analysed separately. However, such a difference is poorly defined in climate-agriculture studies, which creates a gap limiting agricultural adaptation policy inclusion and climate-risk management strategies.

### 1.2 The Research Problem and Method of Approach

Northern Ghana is very susceptible to climate change owing to several elements such as high dependency on rain-fed farming, abject poverty, and environmental destruction that amplifies the Harmattan season (Acheampong et al., 2014). With the increasing temperature and fluctuating rainfall, communities which rely on agriculture are finding other ways of ensuring livelihoods. These issues place a high pressure on policymakers in designing adaptation strategies to effectively respond to emerging climatic risks and not just rainfall variability.

The Harmattan is a transparent and well-documented element of the West African climatic systems but, its dynamic aspects and its impacts on agriculture are under-examined in the climate-agriculture studies today. The existing literature and policy-oriented evaluations have the tendency to integrate the effects of the harmattan in greater macro-level storylines of dry season or drought, and overlook the unique routes through which increased winds, dust, and humidity oppression impacts agricultural systems. These literatures serve as guidelines and reference points for most adaptation and agricultural resilience initiatives and may not fully integrate the implications of the changing Harmattan condition. This will exacerbate the already existing problems of food security, soil conservation, water management and rural livelihoods. In regions where agricultural systems are largely climate-sensitive, presents a significant policy gap.

It is against this background that this research poses the following main research question: **How have the conditions of the Harmattan winds in Northern Ghana escalated over the past decades, and what are the consequences of the escalation on the agricultural systems?**

Answering this question is the objective of this research, which employs a qualitative case-based analytical approach. The study uses the Northern Ghana as a study region to explore the broader theoretical issue of how the dynamics of an intensifying Harmattan season contribute to agricultural stress. The research utilizes a combination of climatological data, agricultural reports, and the existing scientific literature to explore the interaction of atmospheric dynamics and agricultural outcomes.

The method is hence diagnostic and integrative. The conceptual analytical focus is to investigate the question of whether changes in dry-season atmospheric features; especially temperature, humidity, wind, and dust states and how they can be usefully related to known agricultural stress responses in Northern Ghana. The research relies mainly on secondary data and institutional records.

Climate data are provided by the Ghana Meteorological Agency (GMet). These records give an understanding about the trend of temperatures, moisture levels, wind patterns and the variation in rainfall in the Northern Ghana. Agricultural data are based on reports of the Ministry of Food and Agriculture (MoFA), regional production data, vulnerability data, and dryland agricultural analysis reports by national and international organizations. These materials record the performance of crops, limits to irrigation, degradation of soil and locally, climatic stress. They are discussed as an indication of repeated patterns and institutional acknowledgement of environmental exertions.

Also, peer-reviewed sources concerning Harmattan circulation, dust transport, evapotranspiration processes, and drylands agronomy are reviewed systematically. Based on the sources mentioned, the study then moves through a series of analytical stages.

The analytical process follows a two-stage process that is interconnected. The study first interprets available climatic records and regional climate syntheses to determine whether there is any indication of changing conditions in the region. There is a focus on temperature rises, changes in the degree of humidity, prolongation of the dry-season period, and variability due to winds. The aim is to understand whether the description of the characteristics of the Harmattan as a stable seasonal phenomenon still suffices or new variability is slowly becoming reflected in the records of climate.

Second, the research performs a thematic analysis of agricultural effect. Reports and agronomic research are checked to detect mention of wind erosion, moisture stress during the dry season, impact of dust on crops, irrigation load, as well as post-harvest exposure. These results are arranged based on the vulnerability pathways identified in this paper; soil degradation, evapotranspiration stress, and physiological crop effects.

The analysis focuses on problematic questions of whether climate records and agricultural reports exhibit consistent trends, and whether there are any established scientific processes of how the condition of the Harmattan can affect agricultural performance. The analysis is thus an evaluation of the coherence across domains as opposed to deterministic causality. The rationale for this approach is methodologically justified on several grounds.

There are three main reasons why a qualitative, literature-based approach is suitable. To start with, the research question addresses a conceptual gap of climate-agriculture research, the limited focus on wind-induced atmospheric stress in vulnerability models based on rainfall. Such a gap cannot be filled with simple statistical modelling but with integrative synthesis.

The stress of harmattan is multi-mechanism, and thus cannot be merely analysed based on the precipitation. These mechanisms can be studied in a holistic manner using a documentary and interpretive approach.

Northern Ghana is a structurally weak dryland system having rich qualitative evidence of environmental change in the form of institutional records, climate records and farmer accounts. The synthesis of these materials allows a grounded but analytically sound development of emerging risk. Despite its strengths, the approach presents some limitations.

Since this research is based on secondary climate data, it does not produce original field data. The availability of meteorological data at the stations may differ and institutional agricultural reporting systems may not directly quantify wind damage. Moreover, agricultural stress and climate variability are not directly causally related.

However, the triangulation of climatological records, institutional documentation and peer-reviewed agronomic literature, enhance the credibility of the analysis, and permits a thoughtful yet significant inference on the issue of the agronomic exposure to the Harmattan. The study aims to assess implications of the intensification of Harmattan for an effective climate adaptation plan in Northern Ghana and the resilience mechanisms of agriculture and a climate-risk governance framework.

# CHAPTER II

# LITERATURE REVIEW

## 2.1 Climate Hazards and Slow-Onset Climatic Stressors

There are two types of climate hazards: rapid-onset events and slow-onset processes (Iskandar et al., 2021). Slow-Onset Climatic Stressors such as rise in sea level, desertification, glacial melting, salinization, and Harmattan that have cumulative effects over years or decades (Margaret, 2017). Although rapid-onset hazards have received substantial analytical and policy focus because of their immediate and conspicuous effects, slow-onset climatic stressors may have more profound and cumulative implications on livelihoods, ecological and agricultural systems (Iskandar et al., 2021; Margaret, 2017).

Slow onset stressors are characterized by gradual increase, prolonged exposure and compounding effects which are hard to pin down to single events. In the agricultural sector, some of these slow-onset stressors can be seen in desertification, land degradation and harmattan, which have led to soil erosion, loss of organic matter, salinization, and acidification, all of which steadily diminish the productivity of agriculture, livestock, and forestry sectors (FAO, 2025). These stressors are unlike the rapid onset disasters, in that they are insidious and their effects are accrued over a long period of exposure. This manifests itself in the agricultural sector in the form of the loss of nutrients, a decrease in the soil structure over the year, and the loss of the water-retention capacity, which negatively affect long-term sustainability without specific events (FAO, 2025; Iskandar et al., 2021). A lot of the literature, however, focuses on slow-onset stress mainly by analysing rainfall decline, which causes direct temperature rise or drought recurrence, and other atmospheric processes are analytically underdeveloped.

Recent literature points to combined risks of heating, wind, evapotranspiration and atmospheric agents such as harmattan in susceptible areas such as Northern Ghana. Compounding interactions such as drought-heat (evapotranspiration effects), drought-windstorms (Philippines), atmospheric circulation changes (Harmattan), and multi-timescale events in dry regions (Northern Ghana) have been observed and compounding interactions have been encouraged by adaptations literature not to rely on individual indicators (IPCC, 2023; Meteorological et al., 2022; Nicholas et al., 2023). This offers a conceptual approach to re-evaluating climatic events like the Harmattan which have a slow-onset nature and are poorly theorized as a hazard in agricultural sectors.

Slow-onset climatic stressors calls for a policy inclusion in national policies when they greatly show clear impacts over time and while still underrepresented in adaptation planning strategies (IGAD, 2023). The Harmattan conditions of Northern Ghana is evident to this. It has slow onset effects and may not be as salient in the framework of disaster response which focuses on rapid onset hazards. This becomes a problem for climate governance particularly in agricultural dependent areas such as Northern Ghana. At this location, persistent environmental stressors could potentially reduce climate resilience and knock the door down on environmental crisis.

## 2.2 Wind, Dust, and Atmospheric Processes: Strong Science, Weak Agricultural Integration

The evidence on atmospheric science is strong on Harmattan dynamics in West Africa such as transboundary dust movement, aerosol loading, radiative forcing, and seasonal circulation patterns (Knippertz & Todd, 2012; Lyngsie et al., 2011; Schulz et al., 2012; Schwanghart & Schütt, 2008). Harmattan periods are confirmed to have low humidity, low-level nocturnal jets that contribute to morning dust activations, suppressed convection over Sahara, and strong radiative processes due to dust absorption (Aziz et al., 2020; Fiedler et al., 2015).

There have been little translations on agricultural risk analysis. Under the influence of the Harmattan winds, precipitation is impaired and air humidity and temperature reach stressful levels. Climate change is causing an increase in temperature that will drive up the evaporative power of the atmosphere, risking to harshen both the soil and atmospheric stress. This would further threaten the viability of crop cultivation in the Northern Ghana. Even though there is clear evidence of atmospheric impacts on agriculture, these wind stressors continue to receive poor inclusion in agricultural vulnerability assessments unlike droughts, floods or storms. Harmattan dust deposits 20-40 percent of annual phosphorus needs in Ghanaian farmlands in north, although this benefit is reduced in bare fields through wind erosion that erodes nutrients, redistributes soil, and increases evapotranspiration, destroys crop canopy, and prevents soil moisture, which is harmful to crops (Breuning-madsen et al., 2015; FAO, 2025).

Health, aviation safety and air quality have been extensively discussed in research on dust in West Africa, but rural agricultural effects have been treated as secondary or anecdotal (Fiedler et al., 2015; Knippertz & Todd, 2012; Schepanski et al., 2017). This disciplinary gap has led to a scenario in which Harmattan is highly documented scientifically and poorly incorporated in the agricultural vulnerability systems. Although there is a significant amount of evidence generated by atmospheric science, these have not been translated to resilience strategies of agricultural systems, to climate adaptation program(s), or to vulnerability assessments or mechanisms. This brings a blind spot in policy integration and adaptation planning particularly in dryland regions.

### 2.3 Agricultural Vulnerability: Rainfall Reliance and Analytical Blind Spots

West African crop models, vulnerability indices, and early warning systems are based on measures of precipitation. Examples of such studies include Standardized Precipitation Index (SPI), which measures exposure and sensitivity in the case of rainfall shortages (Derbile et al., 2016; Tefera et al., 2024). These techniques are helpful in the capturing of drought-related failure but do not capture atmospheric stressors like the Harmattan. The rainfall variability, drought frequency, and temperature extremes are the main production risks that are of priority in studies of agricultural vulnerability in West Africa. Antwi-Agyei et al., (2018) examines household vulnerability in Ghana, attributing poor maize yields to poor rainfall patterns and droughts. FAO, (2025) and World Bank Group, (2020) observe that rainfed agriculture is dependent on both precipitation and the vulnerability indices highlighting the drought warnings across the Sahel.

The overwhelming impact on climate adaptation policy has been that of rainfall-based indicators (Kchouk et al., 2023). National systems and policies often overlook experiences of wind-related disasters and slow-onset events and focus on drought-related events creating a “drought monitoring gap”. Consequently, there are mismatches in the official climatic data and blind spots with respect to the impacts of local climate change and local climate resilience strategies and vulnerabilities (Kchouk et al., 2023; Van Loon et al., 2024).

These literatures and techniques are effective in explaining drought crop failure, but they fail in normal rainfall conditions with atmospheric stress. Harmattan stimulate evapotranspiration in West African drylands, drying the soil moisture despite the adequate rainfall (Schumacher et al., 2022). Dryland research outside West Africa validates the idea that wind velocities enhance the rate of evaporation, and decreasing water availability (Davarzani et al., 2014).

Exclusion of wind variables is a risk of under-estimating threats in areas where the intensification of Harmattan is high. Although rainfall models prevail, new trends are attributing climate change to high-level dust emissions and dry winds, which increase erosion and moisture stress on Sahel agriculture. Wind measures like low-level jet strength could be a solution to this vulnerability gap by being incorporated into vulnerability frameworks. Need to broaden vulnerability frameworks and policy planning to incorporate atmospheric indicators, to enhance scientific-policy interaction and decision-making. This will give a robust overall insight into agricultural risks in Northern Ghana and other comparable dryland areas related to climate.

### 2.4 Drought Frameworks and the Misclassification of Harmattan Impacts

The semi-arid climate risk assessment is centred on drought-based models which combine a broad set of stressors as droughts. Van Loon et al., (2024) denounces this as a ‘continuum’ oversight, where the processes occur as meteorological droughts accumulate on antecedent states without considering individual processes such as propagation lags and feedbacks. Stress processes at normal or near-normal rain levels are often modelled by drought frameworks using standardized precipitation indices, soil moisture proxy or rainfall anomalies, that are unable to capture processes of stress.

When one takes harmattan as a drought or dry season subdivision, it cuts across lines in West Africa. Harmattan is not dependent on rain failure and reaches its peak between November and March due to Saharan high temperatures and night jets. Its processes are; high winds, dust aerosols, inhibition of relative humidity, causing desiccation and evapotranspiration rather than lack of precipitations. Harmattan-associated stress can be pre-rainfall, post-rainfall, or rainfall independent during land preparation, irrigation, and post-harvest periods (Knippertz & Todd, 2012; Lyngsie et al., 2011).

This misclassification diverts the research on wind pathways to vulnerability. In combining to drought, it puts adaptation into a blindfold concerning such specific actions as windbreaks or irrigation timing, even though Harmattan contributes to crop wilting and soil erosion. Models may be refined by the inclusion of process-specific measures. In terms of policy narration, the effects of Harmattan could be included as part of drought, which may restrict the ability of adaptation strategies to be effective (Řeháček et al., 2017). Harmattan should be distinguished as a lone atmospheric stressor to enhance a clear development of a more targeted policy intervention to incorporate windbreak establishment, irrigation planning, soil conservation measures and early or seasonal advisory or warning systems.

## 2.5 Climate Adaptation Policy and Agricultural Risk Governance

Ghana's climate adaptation policy has always focused on rainfall, drought, food security and water management or development (UNEP & UNDP, 2019). The national adaptation mechanisms and agricultural resilience programs in Northern Ghana has recognised climate-related risks to livelihoods and food production since this region is greatly dependent on rain-fed agriculture (UNEP & UNDP, 2019). Yet, these prevailing strategies and frameworks are still strongly geared towards the risks of precipitation and drought effects. Rainfall variability is a key measure of the vulnerability of agriculture in Sub-Saharan Africa. Designing a climate policy framework in this region, always reflects on a broader trend of climate adaptation plan (Marenya et al., 2024). This has contributed to improved drought preparedness, early warnings and water management systems and some consideration of atmospheric drivers such as the suppression of humidity, wind erosion, dust and evapotranspiration (ET) associated with the Harmattan conditions.

It is suggested in the emerging literature on climate risks that it will be necessary to have a more comprehensive understanding of climate risks than just rainfall deficits to have effective adaptation plans (Marenya et al., 2024). Risk processes for agriculture should incorporate atmospheric indicators to enhance the ability of policy makers to detect and address multiple interacting climate indicators impacting on agriculture. This is significant particularly in Northern Ghana, where Harmattan activities are coinciding with important activities of the agricultural production process like land preparation, irrigation and post-harvest management (Acheampong et al., 2014; Lyngsie et al., 2011).

This is important policy blind spot because the integration of the Harmattan dynamics into Ghana's adaptation planning is poor. Addressing this gap, it would do an effective job of contributing to a comprehensive climate-risk governance, a robust approach for agricultural resilience and advanced climate adaptation interventions in a vulnerable dryland context.

# CHAPTER III

## CASE PROFILE: NORTHERN GHANA IN A CHANGING HARMATTAN REGIME

### 3.1 Northern Ghana and Agricultural Exposure to Climatic Variability

The Northern Ghana, comprising of the largest portion of land mass combined, with the Northern Region (25,000 square kilometres, before division), Upper East Region (8,842 square kilometres) and the Upper West Region (18,476 square kilometres) (GSS, 2013). It borders the Brong Ahafo and the Volta regions to the

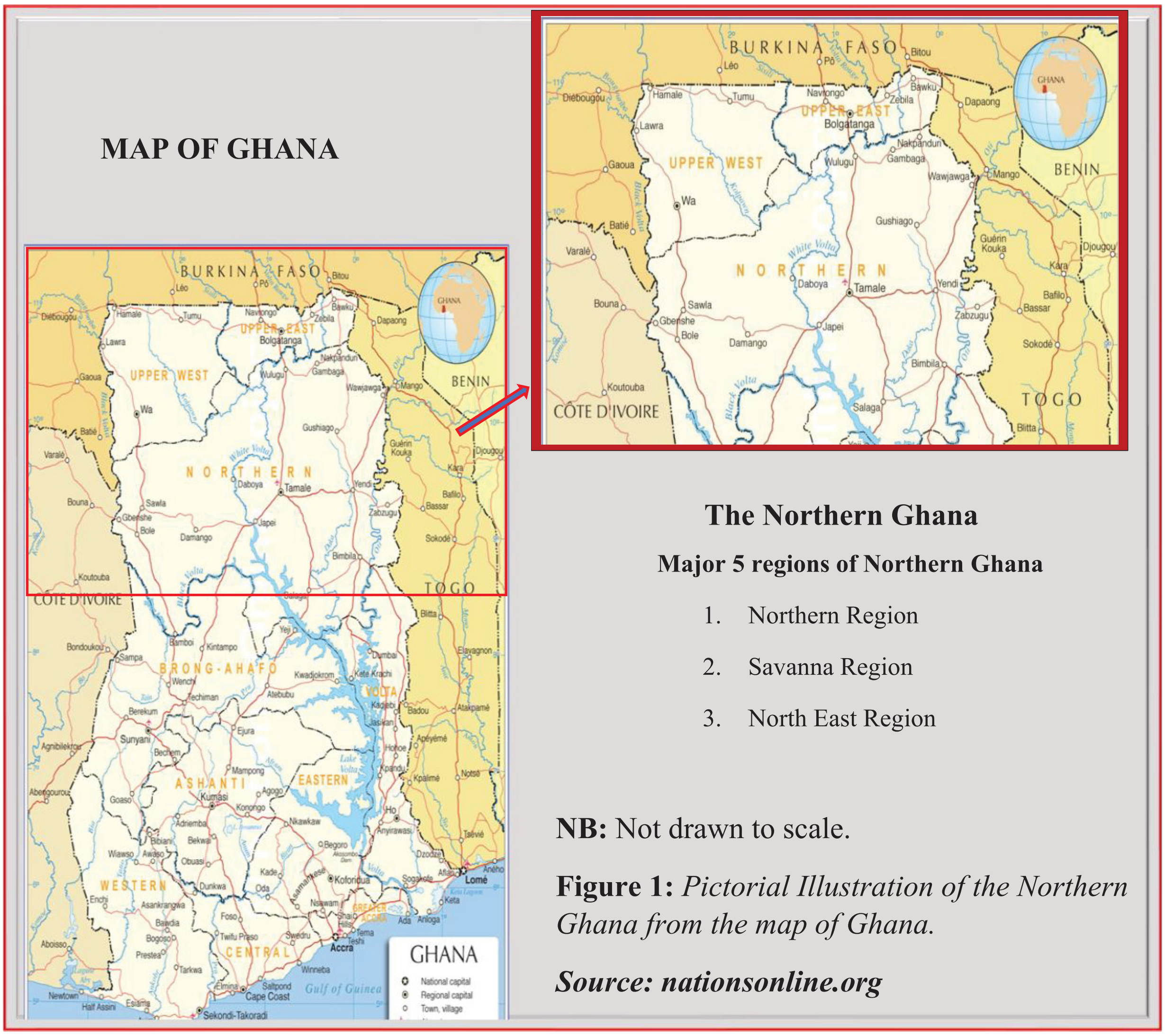


**Figure 3.1**: The Northern Ghana from the Map of Ghana

south, and the neighbouring nations, such as the Republic of Togo to the east, Cote d' Ivoire to the west and Burkina Faso to the north. In December 2018, the Savannah Region and North East Region were created from the Northern Region. The Northern Ghana today, comprises of 5 regions of the 16 regions of Ghana with several districts. Approximately 5.5 million people live in Northern Ghana and the region plays a significant role in Ghana's agricultural sector, providing 50% agricultural products in the country (Raymond Ohene Gyan, 2024). However, this region experiences a growing climatic variability posing a threat to its agrarian agricultural economy.

Ghana has a tropical climate with two main seasons: the wet season and the dry season. The wet season in Ghana begins in April and ends in September while the dry season has lower humidity and lower rainfall (Dr. Kate Gyasi et al., 2025). The excessive dryness in some regions of Ghana is attributed to the northeast winds known as the Harmattan winds (Lyngsie et al., 2011). At the end of the dry season, in March, the highest temperatures are recorded. Temperatures can fluctuate, becoming hot or extremely hot during the day and frigid at night (Antwi-Agyei et al., 2018; Lyngsie et al., 2011). These conditions are more severe in Northern Ghana than in coastal areas (*Figure 3.3*).

**Figure 3.2**: Intensifying Harmattan affecting air quality and damaging crops in Northern Ghana. **Source**: https://metrotvonline.com/changing-weather-patterns-effects-of-harmattan/

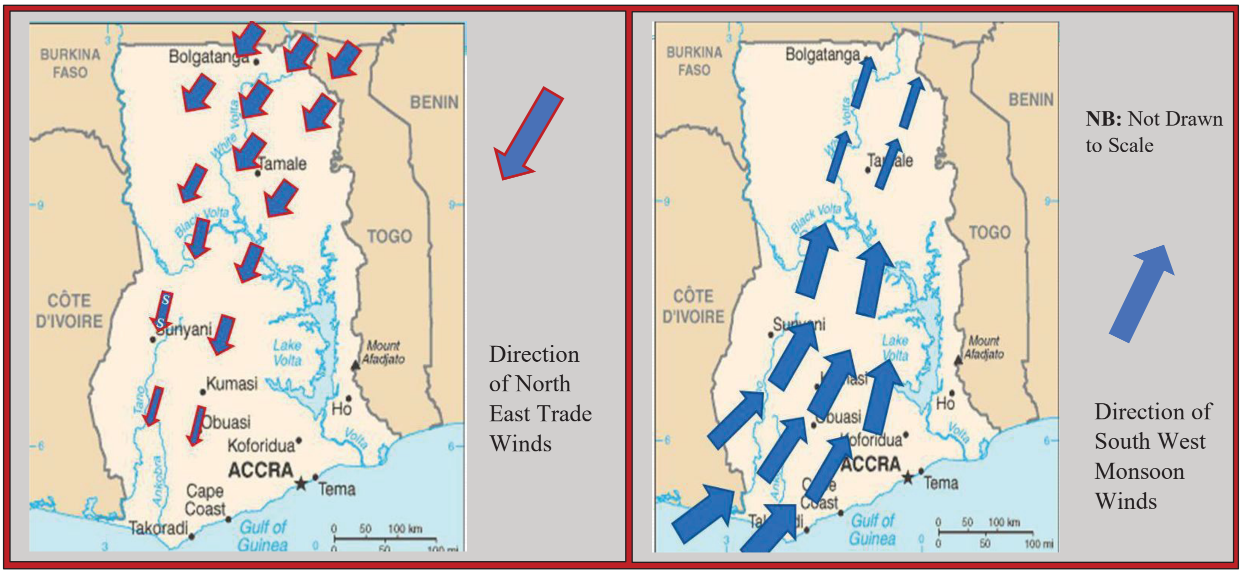


**Figure 3.3**: Position and movement of the Northeast Tradewinds and South West Monsoon Winds in Ghana. ***Source****: GHANA PAKISTAN PARTNERSHIP. HEADLINES EDUCATIONAL CENTRE KUMASI-GHANA, (2014)*

Northern Ghana, an area made up of Guinea and Sudan savannah agro-ecological zones, is one of the most climate-sensitive agricultural zones in Ghana. In the Northern Ghana, the climate varies between 8deg. N, to lat. 11deg. N, but they have lesser adaptive capacity since poverty, infrastructural incompetency, and overdependence on rain-fed agriculture are prevalent (GoG & UNDP, 2019; World Bank, 2011).

Smallholder agriculture is also common where the crop schedules are closely tied to the yearly climatic cycles. Dry season is slowly overlapping the agricultural practices such as land preparation, dry-season vegetable cultivation and livestock grazing. The Ministry of Food and Agriculture (MoFA, 2018) of Ghana and FAO data show that recent years have witnessed a massive increase in dry-season irrigation both to irrigate rice, soybean, and horticultural crops and exert further pressure on already limited water resources (FAO, 2014; MoFA, 2018).

GMet observations have also recorded increased and more intense episodes of the Harmattan, whereas Northern Ghana is commonly identified as a climatic hotspot, analysis of the agricultural risk profile still remains biased towards rainfall deficits and drought, and little attention is paid to the atmospheric processes of the dry-season, including the Harmattan. This creates a potential gap of emerging climatic realities and national policy integration.

### 3.2 Agro-Ecological Characteristics and Agricultural Systems in Northern Ghana

Northern Ghana is typified with sandy to sandy-loam soils, low natural organic matter, and sparse vegetation cover during the dry period (Siaw, 2001). The region's vegetation cover consists of mixed formations of fire-resistant trees and shrubs.

Cropping season in this area is synchronized to the onset and offsets of rainfalls but the soil preparation, irrigation and post-harvest processing often coincides with the months of Harmattan. The main method of operationalization of these processes is rain variability and drought indices (Antwi-Agyei et al., 2018; Lyngsie et al., 2011). Nevertheless, regional diagnostics show that an increase in temperature and length of dry season is becoming a more influential factor of yield stress (IPCC, 2022a, 2022c). Thus, agro-ecological regime may be moving out of rainfall-based vulnerability to multi-variable atmospheric stress. This current shift has effects on agricultural planning and climate adaptation approaches that usually continue to focus on rainfall indicators of risk.

According to satellite reanalysis and regional meteorological datasets (GMet), interannual variation has been observed with regard to onset, duration and intensity. Recently, West African syntheses have documented a higher persistence of dust plumes and a longer dry-season (GMet, 2024; WMO, 2023). Atmospheric science has a strong quantification of the dynamics of the Harmattan but the wind velocity, dust load, or the dry minimal of humidity have rarely been used as independent yield variables in agricultural modelling. Instead, Harmattan is largely explained as a background of a season and this posed the danger of misjudging climatic exposure by omitting wind variables.

Within this agro-ecological context, agricultural systems in Northern Ghana are systems of production which have adjusted to external factors (Siaw, 2001). Northern Ghana has two major types of farms which are compound farms and bush farms. The farming systems prevalent in the region are mixed cropping, mixed farming, inter-cropping and monocropping. The crops cultivated in the compound farms include cereals (maize and sorghum), tobacco, yam and vegetable whereas those cultivated in bush farms include cowpea, groundnuts, Bambara groundnuts, maize, sorghum, millet, yam and cassava. Cotton is cultivated as a cash crop.

The bush farms are based on the bush fallow system in which cropping and fallow periods are alternated. Increased demand for agriculture products and industrial raw materials, from rapid human population growth, has caused the fallowing period to be reduced. Encroachment has been a concern to environmental management. These problems intensify as the Harmattan intensifies.

Under these conditions, Harmattan winds in northern Ghana have intensified causing severe disruption in agricultural systems by aeolian soil erosion, evapotranspiration, and physiological impacts of crops (Lyngsie et al., 2011). These structural and agro-ecological features form the necessary context for understanding emerging empirical evidence of climatic change in the region, and specifically changes in the intensity, duration, and behaviour of the Harmattan season in Northern Ghana.

### 3.3 Findings: Evidence of Harmattan Intensification

The World Meteorological Organization has recently released State of the Climate in Africa reports, which report rising warming trends in West Africa, which are also associated with increased variation in the seasonal transitions. Although the total annual rainfall has its spatial heterogeneity, the accounts focus on higher frequency of dry spells and irregularity in the phenomenon of monsoon onset, as well as, decline.

In the target year of 2024 and a focal point of Tamale, Northern Ghana, I determined the trends in temperature and rainfall between 1991 and 2024 using the data of GMet (GMet, 2024). Evidence of recent climate data of Northern Ghana further illustrate these changing dynamics.

The total annual and seasonal rainfall variations in Ghana and Northern Ghana are shown in *Figure 3.4*. The distribution of rainfall was majorly normal to below normal in Ghana in 2024 (GMet, 2024). The annual rainfall recorded in Tamale

(920 mm), as compared to its Long-Term Mean (LTM) of 1076 mm. GMet, (2024), shows that Ghana has a total annual rainfall of 1133 mm in 2024 that is the lowest recorded since 2020 and also below its long-term mean (LTM) of 1214 mm. Seasonally, rainfall was relatively normal to below normal.

Tamale readings show the great inter-annual variability in rainfall pattern by demonstrating how the range of yearly rainfall varies significantly among years. Even though this is just one point in the bigger changing curve, the 2024 data point appears to be lower compared to the LTM, indicating an almost average or slightly lower than average year of rainfall compared to the LTM. At the moment, Northern Ghana's rainfall patterns are unpredictable and lack a consistent monthly pattern throughout the year. In addition to these changes in rainfall, temperature trends provide the evidence of climatic shifts. The records show.

The fluctuations seen in rainfall reiterates policy concerns still existing around agriculture vulnerability and fragility in the area. However, the emerging climate challenges cannot be explained alone by rainfall trends. This calls for the need for an extended climate risk assessments to better include atmospheric conditions and wind related risks such as the Harmattan.

The temperature trend of Tamale, the centre of Northern Ghana warming 1991-2024 (*Figure 3.5*) is increasing each day. Maximum (MAX), Average (AVG), and Minimum (MIN) are the three-temperature metrics that are represented by each graph in *Figure 3.5*. According to the data, the highest annual temperatures are usually approximately the same or slightly lower than the Long-Term Mean (LTM) (GMet, 2024).

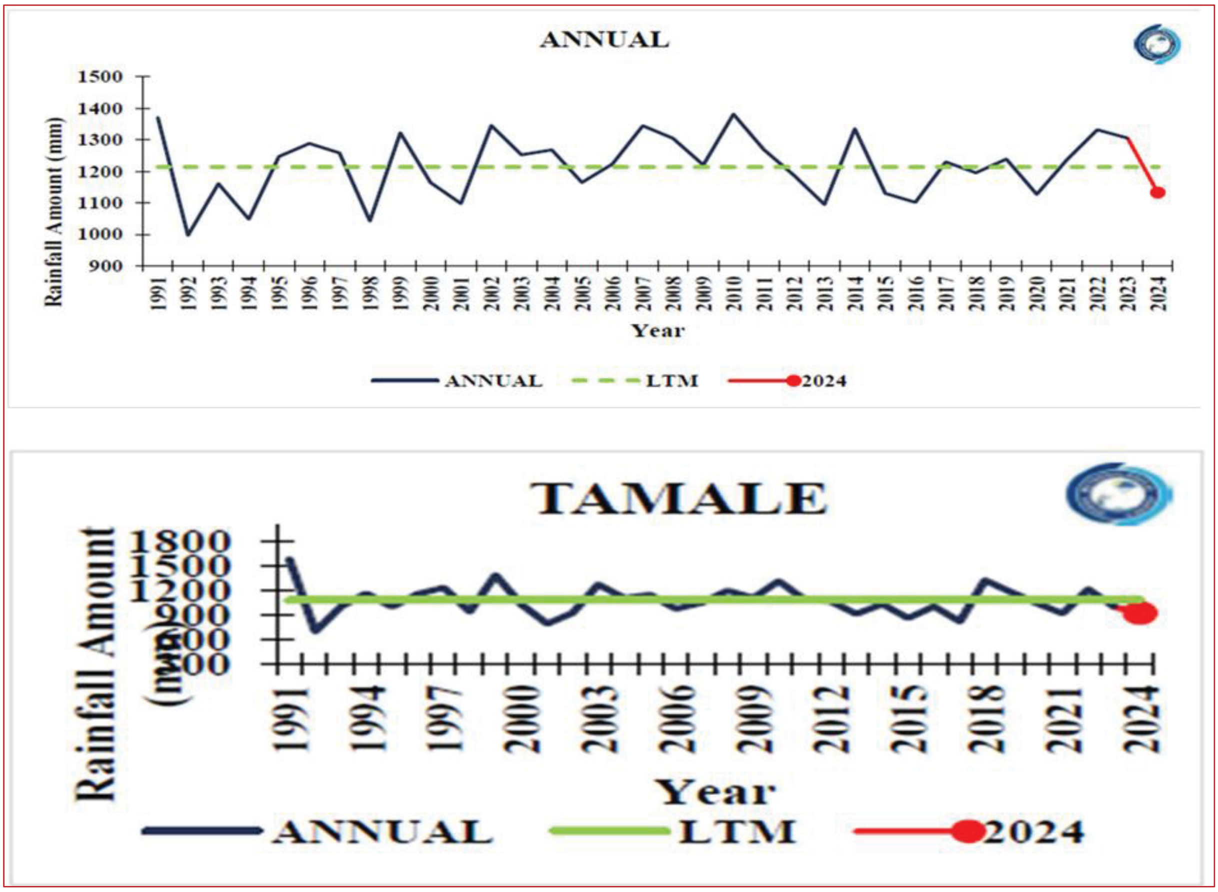


**Figure 3.4**: Trends in Annual Rainfall for Ghana and Northern Ghana, Tamale. The red marker shows the 2024 temperature record. **Source**: GMet, (2024).

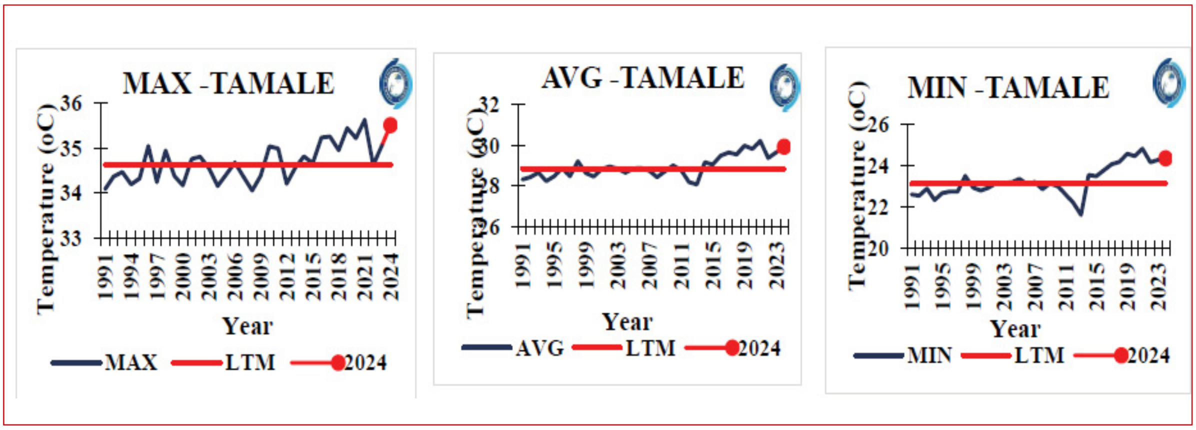


**Figure 3.5:** Trends in Maximum, Average and Minimum temperatures in the Northern Ghana. The red marker shows the 2024 temperature record. **Source**: GMet, (2024).

A more significant growing trend in maximum temperatures starts between 2007 and 2008, and by 2024, maximum temperature is far much higher than the LTM, which means that the year would have warmer peaks. The trend in maximum temperatures of Tamale also exhibits a clear increasing tendency, especially during the second half of the period examines, which suggests that every year, Northern Ghana is slowly experiencing warmer peak temperatures.

Practically, although the Harmattan inherently is associated with a high range of diurnal temperatures (hot days, cool nights, etc.) as the air is dry, and the skies are clear, the overall climate change trend is probably affecting the trends. Northern Ghana, even more directly exposed to the Sahel, is forecasted to undergo faster warming and extreme Harmattan compared to southern regions of Ghana, which would further intensify the "hotter highs" and warmer lows even during and after the dry Harmattan season. This is the reason why in 2024 Ghana recorded the highest maximum temperature of 35.5 degree Celsius in Tamale. Tamale recorded the highest average temperature of 29.9 degree Celsius (GMet, 2024). Alongside the increase in temperatures, data on humidity levels during the months of the Harmattan season indicates atmospheric stress. Agricultural productivity, irrigation demand and climate adaptation are all affected when temperature rises. These trends pre-inform that future agricultural resilience strategies are at risks and may need to consider atmospheric stress, temperature and traditional rainfall indicators.

Assessment report number 6 of the Intergovernmental panel on climate change (2022) concludes with high confidence that there has been persistent warming in West Africa in the past few decades with frequent and severe extreme heat events. Notably, the temperature patterns are more spatially uniform as compared to rainfall patterns in the area.

This regional warming signal can be observed in the dry-season of Northern Ghana. According to seasonal climate bulletins, there are recurrent events of high mean and maximum temperatures in the period of Harmattan months, along with constantly low relative humidity rates. Dry-season atmospheric dryness is a feature even in years that do not experience bad rainfall deficiency.

According to Europe & Africa (2025) report on Climate in Northern Ghana, this part of the country records an average daily maximum temperature of 34 degrees and is one of the warmer regions in Ghana (*Figure 3.6*). A complicated mix of environmental, health, and economic issues are brought on by the year-round warmth and heat, which worsens during the Harmattan season and has few really tropical and humid months. Temperatures drop in August and rise in February to March, which is often the most destructive Harmattan season with the highest recorded levels of dry, dusty air in Northern Ghana (Europe & Africa, 2025). The average annual temperature in the Northern Ghana is 29 degrees Celsius. It is highest in March at 33 degrees Celsius and lowest in August (*Figure 3.7*).

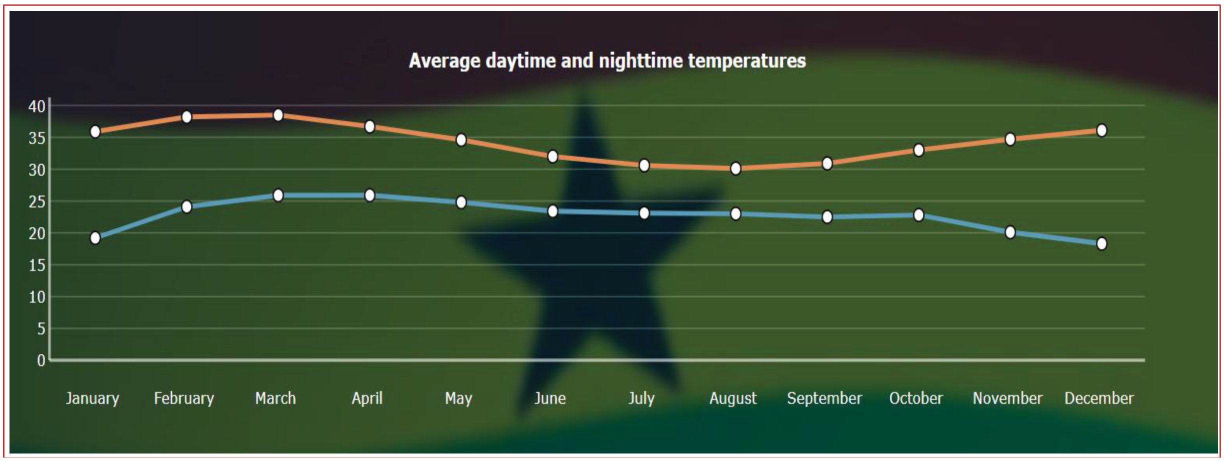

**Figure 3.7**: Average daytime and night-time temperatures in Northern Ghana. **Source:** https://www.worlddata.info/africa/ghana/climate-northern.php

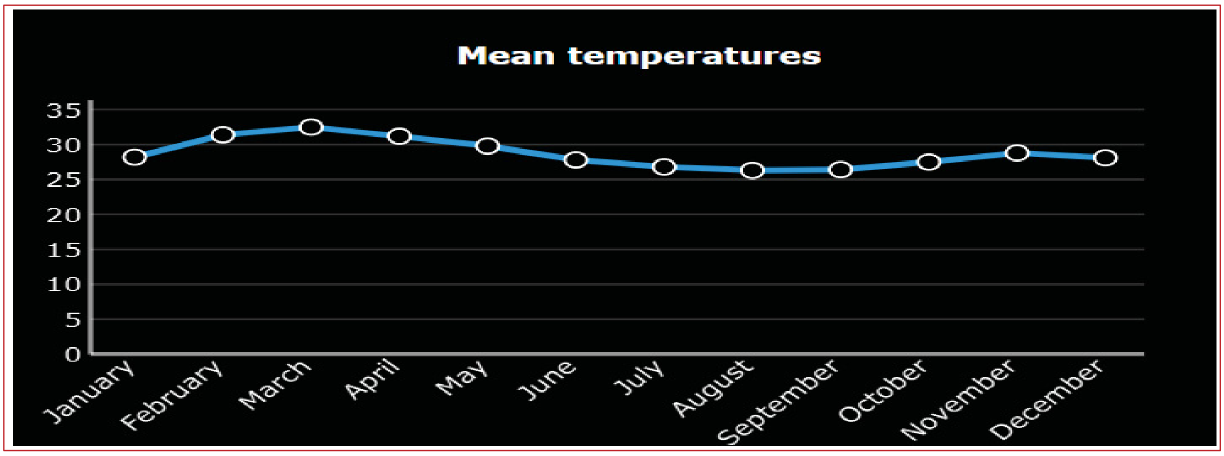

**Figure 3.6**: Average Annual Temperature in Northern Ghana. **Source:** https://www.worlddata.info/africa/ghana/climate-northern.php

In the far north of Ghana, maximum temperatures of 32deg. C (90deg. F) are common (Europe & Africa, 2025). Humid conditions also prevail in the north of the country during the rainy season. However, during the harmattan season, humidity in the north drops to as low as 25 percent (Pelletiere, 1990). Literature in atmospheric science goes further to state that warming increases the demand of evapotranspiration, especially in combination with low humidity (Knippertz & Todd, 2012). However, moisture stress due to humidity is often neglected and rainfall variability often forms the core of Ghana-based agricultural vulnerability studies.

### 3.4 Why the Intensification of the Harmattan and Trends in Climate Change in Northern Ghana

Climate change in Northern Ghana is leading to warmer seasons in all seasons, including the season of the Harmattan. This is particularly affecting the Harmattan season, especially at night. The effect on dust is multifaceted and may increase environmental, socio-economic, and health problems (GMet, 2024). While some evidence suggests a reduction in the severity of the traditionally cold Harmattan, the intensification of the Harmattan season is not universally agreed upon (File & Derbile, 2020).

#### 3.4.1 Climate Change Vulnerability of the Northern Ghana

The climate change effects are very dire in the North regions of Ghana because of such factors as high dependence on rain-fed crop production, poverty, and environmental deterioration (Acheampong et al., 2014). Compared to the rest of Ghana, poverty rates are much greater in the northern region (Adaptation Learning Programme (ALP) and Care International, 2013).

With the increase in temperatures and the fluctuation of rainfall, communities that rely on agriculture are exploring alternative ways of ensuring livelihoods. The main factors that have contributed to the vulnerability are high poverty, lack of education, poor agricultural activities, and geographical location, which amplifies Climate Change and worsens the Harmattan season.

### 3.4.2 Natural Climate Variability of the Northern Ghana

The GMet data of Ghana indicate a reduction in the early-season rainfall and delayed start of the rainy season, which is associated with the duration and intensity of Harmattan. The patterns of rainfall are complicated and affected by natural atmospheric and oceanic effects such as **El Nino and La Nina, Indian Ocean Dipole (IOD)** events that may affect global weather patterns such as the Harmattan season. Northern Ghana, in West Africa, is vulnerable to these teleconnections. El Nino and La Nina processes are not usually consistent, which adds to the unpredictability when it comes to seasonal variations (Akumun, 2025).

Once again, the **West African Monsoon systems** and the **Inter-Tropical Convergence Zone (ITCZ)** are susceptible to natural change and thus there are variations in the seasons and timing of the Harmattan. Although natural variability is not sufficient to explain why irregular climatic patterns have been escalating lately, it enhances the impacts of other causal factors.

Recent satellite and ground meteorological observations in Northern Ghana indicate that there is a history of growing dust load and prolonged periods of the Harmattan as reported by Ghana Meteorological Agency (GMet). There is a complex feedback of climate change: global warming accelerates the process of desertification in the Sahel and declines vegetative cover, leading to even greater dust emissions and extending the influence of the Harmattan (GMet, 2024).

While these observed trends in climatic variables provide some evidence of changes that may be occurring, it is necessary to examine how these changes are manifested as specific pathways of agricultural stress within the Northern Ghana and beyond.

Harmattan-driven Sahara dust outbreaks contribute about 80% of dust emissions with equatorward expansion having a direct effect on the West African monsoon area and lowering net radiation to less than 100 $Wm^{-2}$ by the use of low down-welling short-wave radiation (Fiedler et al., 2015; Knippertz & Fink, 2006; Siaw, 2001). These radiative changes interfere with land-atmosphere interactions which are important in the retention of soil moisture in dry seasons.

In Northern Ghana, 99.1% of farmers are using rain-fed agriculture systems (Antwi-Agyei, 2012). These already existing sensitivities compound dangers once augmented conditions of the Harmattan become an additional stressor that further strains water supply.

Together with the dynamics of dust and wind caused by Harmattan, radiative inputs are minimized (Knippertz & Fink, 2006), creating direct links between atmospheric change and low land use productivity and increased vulnerability of livelihood in climate change impacts. It is necessary to understand the interaction between natural climate variability and a prolonged climate change to effectively design adaptation policies and initiate early warning systems in the Northern Ghana.

### 3.5 Why Harmattan is Distinct from Drought; The Vulnerability Across Agricultural Systems

Most of the studies on agricultural climate risks in West Africa focus on drought, but atmospheric dryness and wind associated processes also create a unique impact even in the absence of rainfall deficits (Siaw, 2001). Rising temperature-induced evapotranspiration is a leading crop water stressor in semi-arid areas, which is one of the main effects of warming (IPCC, 2022; Siaw, 2001).

The quantitative products of Sahel studies are the erosion rates of 1-20 Mg/ha/year of dry-season winds on sandy savanna soils (Ribolzi et al., 2004). Although both Sahel research and Ghanaian studies have adopted aeolian erosion and rainfall variability as their primary vulnerability factors, incorporating radiative and wind effects such as (Antwi-Agyei, 2012; Knippertz & Fink, 2006) studies would widen the range of vulnerability models of the rain-fed systems in Northern Ghana. The Harmattan further introduces a new trend of vulnerability in farming systems together with the available drought stress.

Harmattan dynamics in Northern Ghana are determined by the type of crop, mode of production, and crop-livestock mixing mostly found in the Guinea-Sudan savanna zone (Knippertz & Fink, 2006). Farmers producing cereals by rain-fed methods, who make up over 95% of production, specifically, maize, millet, sorghum and legumes are particularly susceptible to the effects of Harmattan, including low relative humidity (<10%) and harmattan winds that result in loss of soil moisture and increased evapotranspiration following the harvest, disrupting the shallow land preparation period preceding the rainy season in May-June (Antwi-Agyei, 2012; Wiredu et al., 2010). This is further enhanced by the topsoil loss on cultivated fields during the months of November-March by the winds, which reflects the erosion tendencies of the Sahelian soils as the bare savanna soils lose 10-50 kg N/ha/year during the same dry-season winds (Ribolzi et al., 2004).

Farmers who irrigate tomatoes, onions and pepper face increased challenges due to increased evaporative demand in the face of increased harmattan winds and temperatures (usually over 35 deg. C), which demand more water by their crops even with added irrigation, and elevating production expenses (Antwi-Agyei, 2012). Compared to rain-fed systems, these farmers experience a higher level of pest pressure because of dust-loaded air and a reduced rate of photosynthesis because the incoming sun radiation is less than 100 $Wm^{-2}$, as recorded during dust outbreaks in the West African region that centralizes in an equatorial direction (Knippertz & Fink, 2006).

In Northern Ghana, agro-pastoral households which integrate cattle, small ruminants and crop residues experience compound stress due to degradation of pastures and deterioration of forage quality during the extended exposure to the dry winds in the Harmattan periods with bushfire risk scalding regrowth (Antwi-Agyei, 2012; Siaw, 2001). Deposition of dust also causes more acidification of soils and less nutritive value of standing hay, necessitating destocking or migration to interfere with the mixed-system resilience.

It has been demonstrated that wind erosion and desiccation reduce rangeland biomass by 15-25% yearly, and 30-40% of households keep livestock in addition to crops (Antwi-Agyei, 2012; Ribolzi et al., 2004; Wiredu et al., 2010). This underscores the fact that harmattan is not an isolated event but a circulation pattern that transports Saharan dust and desertification southward and wash away soil fertility, raises the rate of irrigation of vegetables, and degrades pastures making the region more vulnerable to changes of gradients along the farming continuum in Northern Ghana (Antwi-Agyei, 2012; Knippertz & Fink, 2006; Visser, 2004).

It is clear from this chapter that Harmattan impacts cannot be completely explained by employing a conventional drought framework approach alone. This distinction is evident since rainfall deficits primarily influences the design of adaptation policies. This one-way approach may overlook crucial pathways in agricultural vulnerability in relation to wind, humidity suppression, evapotranspiration and dust. Realizing these unique differences will provide a foundation to determine policy implications and adaptation responses in subsequent chapter.

# CHAPTER IV

# AGRICULTURAL IMPACTS OF THE INTENSIFYING HARMATTAN

The intensified harmattan season in Northern Ghana is posing significant threats to agriculture and its methods, making them extremely expensive to operate. Climate change specifically impacts smallholder farmers as it changes weather conditions, including rainfall and temperature (Agyapong, 2024). Emerging reports and literature from Northern Ghana show an increasing irrigation cost, rising expenditure on water for irrigation and a decreased smallholder farmers profit in intensified Harmattan seasons (Agyapong, 2024). The impacts indicate that the intensification of Harmattan is becoming a multi-sectoral problem and thus poses a challenge to agricultural policy.

## 4.1 Systemic Implications and Agricultural Vulnerability

The results of the research indicate that the stronger the Harmattan winds, the more complex and interrelated the stress on the agricultural systems in Northern Ghana (Siaw, 2001). These pressures are not only related to rainfall variations and drought impacting soil resources, crop production, irrigation systems, livestock management and the sustainability of smallholder farming.

This has one significant impact, which is the decrease in soil moisture and topsoil fertility. Land degradation and soil productivity decline have been reported as a major factor limiting agricultural development consistently across the agricultural reports in Northern Ghana (Pierre et al., 2023). The strong Harmattan winds keep on eroding the soil, stripping off its rich topsoil and decreasing its water holding ability. Northern Ghana could be at similar long-term risks if preventive measures are not strengthened, as is reported on neighbouring Sahelian countries, like Burkina Faso and Niger (Ribolzi et al., 2004).

The study also shows that there is no simple link between crop stress and failure of rainfall during Harmattan. In years of moderate rainfall, high temperatures, low humidity and greater dryness of the air cause moisture to be lost from the soil at a faster rate, which can cause seedling death, loss of soil moisture and crop performance (Fiedler et al., 2015; Lyngsie et al., 2011; Raymond Abudu Kasei, 2014). The discovery contradicts the predominant approach of assessing agricultural risks based on rainfall and indicates that air conditions need to be taken into account more in agricultural planning and climate adaptation programs.

The enhancement of the Harmattan is also causing an increase in irrigation needs and production costs. Compared to wet-season farmers, dry-season farmers should irrigate more often to overcome the higher evaporative loss, which leads to greater water extraction costs, fuel consumption and labour requirements (Raymond Ohene Gyan, 2024; Siaw, 2001). Such extra expenses decrease farm profitability and can make dry season farming less attractive. If left to their own devices, smallholder farmers could be increasingly challenged to sustain production under changing climate conditions.

Livestock systems are also impacted by lower quality pasture, less water, and greater exposure to environment stress from dust. Forage is less capable of 'recovery' in extended dry periods and is under extra stress on already vulnerable systems. This has implications for the livelihoods of households, especially agro-pastoral households who rely on both agriculture and animal husbandry production (N. A. F. Agyapong et al., 2022; IPCC, 2022c).

Policy-wise, these results indicate that the current agricultural adaptation policy in Ghana may not sufficiently address the risks of intensification of the Harmattan. Presently, most of the policies are concerned with drought management, variation in rainfall, and flood control while comparatively less policies are dedicated to wind driven climatic processes (MoFA, 2018; Energy, 2022; EPA, 2015; GMet, 2024; MESTI, 2021). Consequently, critical soil erosion, dry atmospheric conditions, crop desiccation and irrigation stress risks in agriculture may not be sufficiently captured by existing adaptation strategies.

The results thus underscore the importance of shifting away from rainfall-based approaches in agricultural and climate policies to a more comprehensive multi-hazard policy-based approach which accounts for Harmattan risks. This would lead to better climate risk assessment, better adaptation planning and make Northern Ghana's agricultural systems more resilient in the long-term.

# CHAPTER V

# POLICY RECOMMENDATIONS FOR AGRICULTURAL SUSTAINABILITY IN NORTHERN GHANA

The results of this research show that most of the existing vulnerability assessments in the agricultural sector in Ghana focus on rainfall variability, drought occurrence and temperature extremes (Antwi-Agyei et al., 2018; FAO, 2021). Although these indicators are relevant, the findings of this study point to the fact that the Harmattan intensified conditions can cause stress to agriculture through other processes such as wind erosion, dryness in the atmosphere, dust exposure, and increase in evapotranspiration. These effects can even be observed during years with non-severe rainfall deficits.

This finding has key policy implications. If agricultural vulnerability is assessed based mainly on precipitation-related indicators, it may be underestimated in the current climate-risk assessments and early warning systems. So, it is important to introduce other atmospheric parameters like wind speed, relative humidity, dust concentration, evapotranspiration rate etc. in agricultural risk frameworks. Incorporating these indicators into climate monitoring frameworks would give a more complete picture of the agricultural risk in northern Ghana, and help evidence-based decision making (GMet, 2024; WMO, 2023).

## 5.1 Implications for Agricultural Systems and Adaptation Policy in Ghana

The findings also indicated that available adaptation options might not be sufficient to address the particular issues that come up during the intensified Harmattan conditions. Ghana's current policy actions are mainly focused on drought management, expanding irrigation and developing water resources (UNEP & UNDP, 2019). The results, however, highlight those agricultural losses can also be due to wind driven soil degradation, crop desiccation and moisture losses, in addition to rainfall deficiencies.

It means that adaptation policies for agriculture need to get beyond a drought-centric focus and include specific strategies to deal with Harmattan-related risks. These may involve the promotion of shelterbelts, agroforestry systems, soil conservation, and conservation agriculture that minimise the loss of soil and moisture during extended Harmattan seasons (FAO, 2025). Ensuring that these approaches are incorporated in the agricultural extension services would enhance the adaptive capacity of the smallholder farmers and make the farming system more resilient.

Among the most important conclusions of this study is that costs of dry-season irrigation are on the rise. Northern Ghana findings show that the higher the intensity of the Harmattan, the more water that is needed by the crop, leading to greater irrigation frequency, higher fuel use, and higher production costs for farmers (Agyapong, 2024; Raymond Abudu Kasei, 2014).

This discovery is directly relevant to irrigation planning. Current irrigation policies mainly aim to increase water availability and irrigation infrastructure. The results, however, indicate that irrigation efficiency and cost are also issues to be tackled by future policy interventions. Improved irrigation technologies making use of water as efficiently as possible, farmer support programs and community-managed irrigation schemes could lower production costs and enhance resilience to rising atmospheric dryness. This would be especially crucial for smallholder farmers who rely on dry season farming to generate household income and ensure food security.

### 5.2 Strong Institutional Coordination and Climate Information Services in Ghana

The study also points to the importance of greater institutional linkages between climate and agriculture agencies. Humidity, temperature, particulate matter concentrations and visibility are some of the parameters that are regularly monitored by the Ghana Meteorological Agency to assess the Harmattan conditions at a particular time (GMet, 2024). But not all of these observations are converted to useful information for farmers.

Thus, it is important that collaboration between the Ghana Meteorological Agency, the Ministry of Food and Agriculture, the district agricultural offices and extension services should be strengthened as a key policy priority. Enhanced climate information services would help farmers decide on the time to plant, when and how to irrigate, when and how to manage livestock, and how to minimize soil erosion (MoFA, 2018; Ali et al., 2021; MESTI, 2021; UNEP & UNDP, 2019). Improving the sharing of Harmattan-related forecasts and advisories would help in proactive adaptation as opposed to reactive adaptation to climatic stress.

### 5.3 Regional Relevance and Future Policy Directions of Research

The results of this study are applicable on a larger scale to the whole of the West African savanna-Sahel area. The environmental conditions are the same and the Harmattan circulation systems do the same in Burkina Faso, Niger, Mali and northern Nigeria (Knippertz & Todd, 2012; Ribolzi et al., 2004). The problems that are encountered in Northern Ghana are thus common problems that affect agricultural sustainability in the region in the face of climatic changes.

The results confirm a growing push in the literature of climate adaptation to consider multi-hazard approaches, and to understand the interactions between rainfall variability, temperature extremes, atmospheric circulation processes and land degradation (IPCC, 2022b; WMO, 2023). Future agricultural and climate policies should therefore focus on using broader climate-risk policies that include atmospheric stressors from the Harmattan in addition to traditional rainfall-based stressors. This would help the vulnerability assessments, adaptation planning, and resilience of agriculture systems in Northern Ghana and other similar dryland areas in West Africa.

# CHAPTER VI

# CONCLUSION

Northern Ghana is experiencing climate change more and more as it is intensified by the Harmattan. This study's results indicate some signs of an intensification of the Harmattan season with longer persistence, as well as higher dry season temperatures, lower humidity, and higher dust content in the atmosphere. The changing atmospheric conditions of the dry season pose a great evaporative demand and environmental stress, which shows that the Harmattan should not only be considered as a predictable seasonal phenomenon but as a dynamic climatic process which has implications on the agricultural system.

The study presents that these atmospheric changes have impacts on agriculture in multiple ways. Increased dry winds and low humidity lead to increased soil moisture loss and wind driven soil erosion and higher temperatures and evapotranspiration lead to crop desiccation, even in near normal rainfall. The intensified Harmattan will also lead to more irrigation needs and higher production costs of dry-season agriculture and pasture degradation and livestock stress. Together, these effects diminish the productivity of agriculture and make agricultural livelihoods more vulnerable of those whose livelihoods are heavily dependent on agriculture which is sensitive to climate.

The results also show that the Harmattan acts as an agricultural risk multiplier. While traditional droughts are more of a precipitation deficit, the effects from the harmattan are through atmospheric processes like wind strength, suppression of humidity, dust exposure and enhanced evapotranspiration. In years where rainfall levels might seem fairly constant, these processes can account for agricultural stress. This shows an essential gap in current climate risk assessments which mainly focus on rainfall variation and drought indexes.

There are three main contributions towards the objectives of the study. The research, first, reveals evidence indicating intensification of the Harmattan atmospheric conditions in Northern Ghana. Second, it illustrates how these atmospheric processes are manifested in agriculture through the degradation of soils, stress to crops, increased irrigation demands, and increased stress to livestock. Third, it identifies the general applicability of the climatic processes associated with the Harmattan, in the context of dryland agriculture systems in the West African savanna-Sahel region.

The study has important policy implications, as well as a scientific contribution. Climate adaptation strategies in Ghana and other parts of West Africa have been largely focussed on the monitoring of rainfall, drought management and the development of water resources. Although these interventions are all relevant, the results indicate that the existing measures are not necessarily reflecting the risk posed by more extreme seasonal wind regimes. Hence, there is a need to include the atmospheric indicators like wind speed, humidity, dust concentration and evapotranspiration rates in the climate adaptation and agricultural planning frameworks, in addition to the traditional rainfall indicators.

Also, the research indicates the need for better linkages between meteorological services, agricultural institutions and the local adaptation planning process. The outputs of the Harmattan monitoring information must be translated to actionable advisories to help farmers make decisions on such aspects as planting dates, irrigation planning, soil conservation, and livestock management. This integration would enhance the effectiveness of climate information services and enhance vulnerable farming communities' adaptive capacity.

The policy implications of the results indicate a need to move towards more comprehensive multi-hazard climate risk policies, which take into account the interplay between rainfall variability, atmospheric dryness, wind erosion and land degradation. Adaptation policies therefore should encourage interventions in the agriculture sector like agroforestry, windbreak establishment, conservation practices in agriculture, irrigation water management and climate smart farming. Specific focus should be placed on the smallholder farmers who are particularly vulnerable because of their lack of resources and are therefore more susceptible to climatic stresses associated with Harmattan.

This thesis has shown that the Harmattan intensification is a new aspect of climate variability that has implications for the sustainability of agriculture in Northern Ghana. Seasonal wind dynamics as a form of climate risk exposure can augment current rainfall-based agricultural vulnerability and climate adaptation policy frameworks with a more solid basis for evidence-based policy. Considering Harmattan related atmospheric processes in the agriculture planning and policy agendas will be crucial to build resilience, safeguard livelihoods and improve food security whilst adapting to the ongoing climate variability in West African drylands.

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