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Climate Change and Wildfire Dynamics in Cocoa Agroforests of Ghana's Semi-Deciduous Zones: Evidence from Adansi North and Offinso Municipalities

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Abstract: Wildfires are becoming increasingly frequent and intense as a result of global climate change, particularly in tropical regions where agricultural and forested landscapes overlap. In Ghana, cocoa agroforests form the backbone of rural livelihoods and the national economy, yet they are increasingly threatened by wildfire hazards driven by climatic variability and human activity. This study examined the effects of climate change on wildfire dynamics in Adansi North and Offinso Municipalities of the Ashanti Region. A mixed-methods design integrated meteorological data (2000–2020), MODIS fire hotspot records, Ghana National Fire Service reports, and surveys of 285 cocoa farmers in the study. Results show a statistically significant relationship between rising temperatures, declining rainfall, and increasing wildfire frequency and duration. Offinso Municipality, located in the dry semi-deciduous zone, recorded higher fire density and longer fire seasons compared to Adansi North, which lies in the moist semi-deciduous zone. Socioeconomic factors such as hunting, on-farm cooking, smoking and negligence were the key ignition sources. Human activities were found to be hunting ($X^2 = 23.5$, $p < 0.0005$), cooking on farms ($X^2 = 21.3$, $p < 0.0005$), negligence ($X^2 = 25.3$, $p < 0.0001$), smoking ($X^2 = 42.1$, $p < 0.0001$), and establishing agricultural plots ($X^2 = 4.6$, $p = 0.200$). Farmers' perceptions of climate change aligned with observed meteorological trends, and indigenous adaptive strategies including constructing firebreaks, community patrols, and bans on dry-season hunting and on-farm cooking were widely practiced. The study concludes that climate variability and human behavior jointly shape wildfire dynamics in cocoa agroforests and calls for integrated, community-based wildfire management, supported by climate-smart agroforestry policies in the two ecological zones of Ghana.

Keywords: *Wildfire Dynamics; Climate Adaptation; Cocoa Agroforests; Indigenous Knowledge; Fire Management.*

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I. INTRODUCTION

Wildfires are a growing global concern, affecting nearly every biome and altering the structure, composition, and function of ecosystems (Gajendiran et al., 2024). Over the past three decades, the frequency, severity, and duration of wildfires have increased across continents, including Africa, where fire is both a natural ecological agent and a socio-economic hazard affecting livelihoods (Ganteaume et al., 2013). Climate change manifested through rising temperatures, declining precipitation, and prolonged droughts has intensified the risk and impact of wildfires (Asante et.al, 2025). Again, anthropogenic factors including burning of slashed weed to prepare land for cultivation, burning of agricultural waste biomass, land-use change, and population growth contribute largely to fire risk in rural landscapes. In sub-Saharan Africa, fire plays a dual role by maintaining the structure of savanna ecosystems but poses significant threats to forested regions, agricultural systems, and settlements (Nsiah-Gyabaah, 1996; Platt, 2015). Ghana's semi-deciduous forests are particularly vulnerable to wildfire due to the increasing unpredictability of rainfall and the intensifying harmattan season (Dwomoh et al., 2019). Wildfires are most prevalent during the dry months of November to March, coinciding with agricultural burning and hunting activities. In cocoa-growing regions, uncontrolled wildfires can devastate plantations, reduce yields, and undermine the sustainability of agroforestry systems (Appiah, 2007).

Cocoa (Theobroma cacao L.) remains Ghana's dominant cash crop, contributing significantly to national GDP and supporting over 800,000 smallholder farmers (World Bank, 2013; Boansi 2013; Ajagun et al. 2022). According to Scudder et al. (2022), cocoa is an economic crop grown in humid tropical areas with many benefits worldwide. Cocoa agroforests, a traditional system integrating shade trees and intercrops offer ecological services such as microclimatic stability, improvement in soil fertility and biodiversity, carbon sequestration and provision of shade for coco trees (Asare et al. 2014; Dawoe et al. 2016; Asigbaase et al. 2019). However, they are increasingly threatened by climatic stressors and wildfires, which destroy tree cover, degrade soils, and disrupt rural livelihoods (Asante et.al, 2025). In recent decades, Ghana's cocoa growing areas has expanded into drier regions, increasing exposure to fire-prone environments (Asumang-Yeboah et al, 2025). Despite the importance of this issue, few empirical studies have investigated the climate–fire nexus within cocoa agroforests, particularly in relation to farmers' perceptions and adaptation strategies to combat climate change. This study addresses these gaps by analyzing wildfire dynamics in two contrasting districts at Adansi North and Offinso representing moist and dry semi-deciduous zones, respectively. Specifically, the study sought to determine the relationship between changes in climatic variables and wildfire incidence, assess the socio-economic, and cultural drivers of wildfire occurrence and document indigenous strategies used by farmers to mitigate and adapt to wildfire risks. The study contributes to understanding the human dimensions of wildfire risk under changing climatic conditions in Ghana by linking climatic data, remote sensing, and local knowledge.

II. MATERIALS AND METHODS

A. Study Site Description

The Offinso Municipality (Fig. 1) is in the Ashanti Region of Ghana, in the Northwestern Dry Semi-Deciduous Zone and lying between latitudes 6°95′N and 7°15′N and longitudes 1°35′W and 1°50′W (Ghana Statistical Service, 2021). With a population of about 77,000, the municipality has a about 48% males and 52% females and agriculture is the main occupation in the municipality, employing about 68% of the total workforce. The region experiences two rainfall seasons from April to June and September to October with average annual rainfall of 1038 mm, while dry season span from November to February, and the average temperature of the area is about 27.5°C (Ghana Statistical Service, 2021). The vegetation in the Offinso Municipality is dominated by tree species including *Celtis mildbraedii*, *Triplochiton scleroxylon*, *Ceiba pentandra*, *Milicia excelsa*, *Khaya ivorensis*, *Terminalia ivorensis*, *Terminalia superba* and *Bambusa spp.* (Bashagaluke et al., 2019). The Adansi North District (Fig. 1) also resides within the Ashanti Region's wetter Moist Semi-Deciduous Zone and occupying about 854 km², representing approximately 4.7% of the Ashanti Region's total land area (Ghana Statistical Service, 2021). Like Offinso, agriculture is the dominant industry, employing about 77% of the workforce due to the region's favorable climate and ecological conditions (Ghana Statistical Service, 2021). The landscape is characterized by flat or gently rolling terrain, with elevations ranging from 300 m to 410 m above sea level. Unlike Offinso's dense undergrowth, Adansi North features a more open environment with a sparse woody understory and a well-illuminated forest floor. *Tectona grandis* plantations and Taungya agroforestry system are prominently practiced in the region. Ochrosols, well-suited for crops like cocoa, citrus, and oil palm, dominate the soil composition and thrive under the average annual rainfall ranging between 1250 mm and 1750 mm, and an average temperature of about 27°C (Ghana Statistical Service, 2021).

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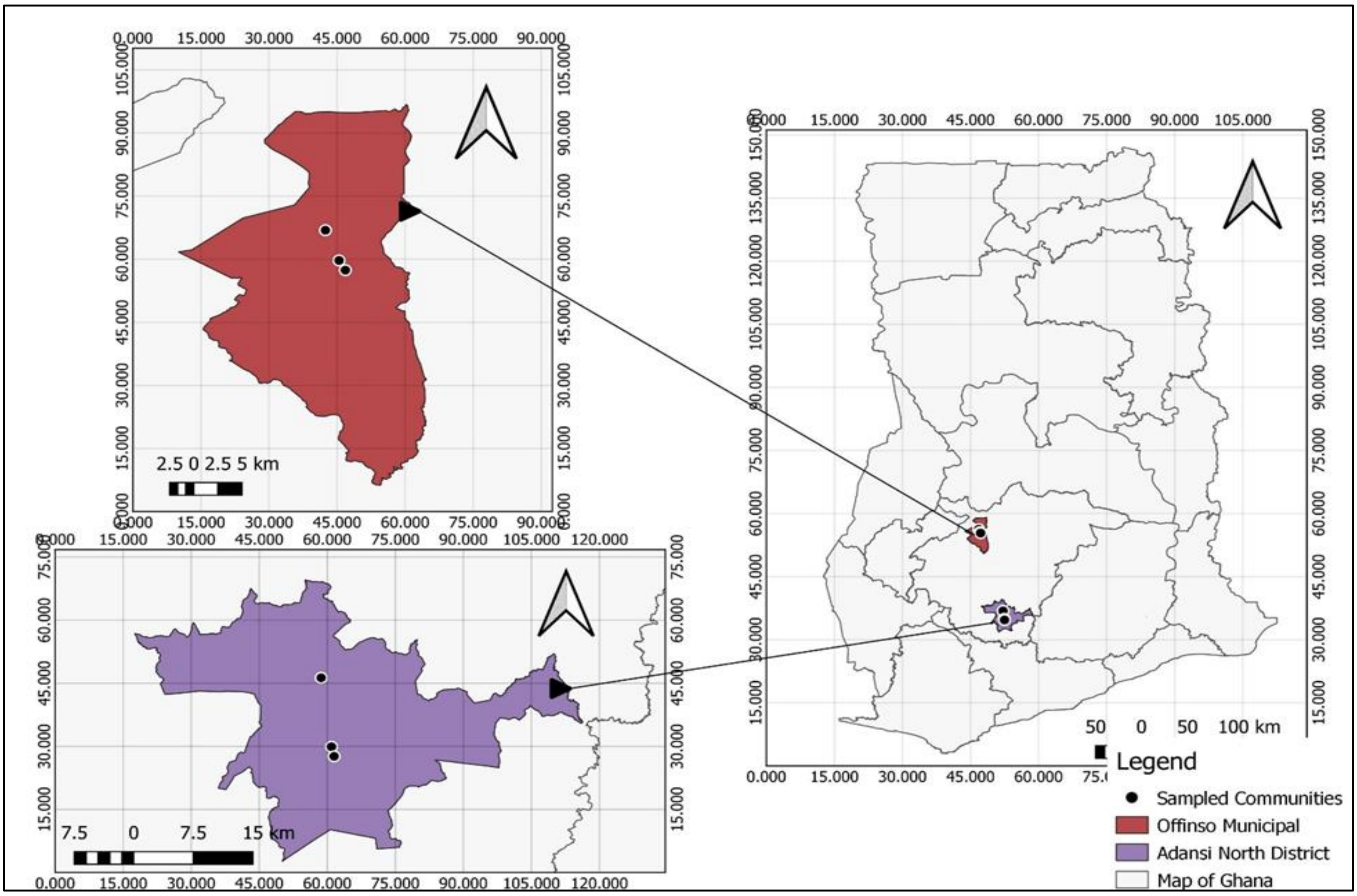

Fig 1 Map of the Study Area Showing the Communities in their Respective Districts

➢ *Data Collection Approach*

This study took an interactive approach to data collection, focusing on conversation rather than simple extraction of information. Farmers were encouraged to share their ideas and questions while researchers captured key details to complete the data collection process.

➢ *Data Sources*

Climate data from 2000 to 2020 were obtained from the Ghana Meteorological Agency and included temperature, rainfall, humidity, and wind speed. Fire incidence data were derived from MODIS (Moderate Resolution Imaging Spectroradiometer) satellite imagery and Ghana National Fire Service records. Socio-economic and perception data were collected through surveys of 285 cocoa farmers, supplemented by focus group discussions and key informant interviews with forestry officials, fire officers, and traditional leaders.

➢ *Sampling and Data Collection*

- Multistage Sampling Strategy

To understand the contrasting effects of rainfall and temperature on cocoa production across Ghana, we employed a multistage sampling approach.

✓ *Stage 1- Ecological Zones:*

Two contrasting ecological zones were purposively selected - Moist Semi-Deciduous and Dry Semi-Deciduous - due to reported declines in cocoa yield and low living standards among farmers in these areas (Afele et al., 2024). Previous research (Hushmiu et al., 2022) focused on a single ecological zone, so this study aimed to compare the experiences of farmers in these two distinct zones.

✓ *Stage 2 -Districts:*

Within these, two districts with established cocoa production were selected based on ease of access, historical yield trends, and well-distributed cocoa-growing communities. These districts were Offinso Municipality and Adansi North District (Anokye et al., 2024).

✓ *Stage 3 -Communities:*

Within each district, three communities were selected based on proximity to the district capital, high cocoa production intensity, readily available farmer data, and past cocoa yield trends. Three communities were chosen from each district: Offinso Municipality (Camp 31, Abofour, and Koforidua) and Adansi North District (Ayokoa, Akrofuom, and Brofoyedu).

✓ *Stage 4 - Individual Farmers:*

Stratified random sampling ensured representation of both male and female farmers. Finally, systematic random sampling identified individual respondents within each gender group. This involved selecting every 11th name on a list of farmers.

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- *Sample Size*

Following Israel (2013), a sample size of 282 was determined using a 95% confidence level and 5% margin of error (equation not shown). This sample was further divided based on gender representation in cocoa production (Bisseleua et al., 2018). In the Adansi North District, 205 respondents were selected (73 females and 132 males). In the Offinso Municipality, 77 respondents were selected (26 females and 51 males).

- *Data Analysis*

Meteorological data were analyzed using trend analysis and regression models to identify correlations between climatic variables and wildfire frequency. Fire hotspot data from MODIS were processed using ArcGIS to map spatial and temporal fire patterns. Quantitative survey data were analyzed using descriptive and inferential statistics, while qualitative data from interviews were thematically analyzed to highlight indigenous adaptation practices.

III. RESULTS

A. Demographic Characteristics

Most respondents were between 30 and 55 years of age, with an average household size of five. Educational attainment was low, with over 60% having only primary education (Table 1). Cocoa farming was the primary livelihood, contributing over 80% of household income. Average farm size ranged between 2 and 5 hectares, and most farmers practiced mixed cropping systems combining cocoa, plantain, and shade trees (Table 2).

Table 1 Demographic Profile of the Respondents in Offinso Municipality and Adansi North District.

Characteristics		Districts		Total Count	Wildfire incidence in farm area		Chi-square (p-value)
		Offinso	Adansi		Yes	**No**	
Gender	Male	45	112	157 (55.1)	138	19	0.24 (0.624)
	Female	38	90	128 (44.9)	119	18	
Age	19-28	2	4	6 (2.1)	5	1	2.772 (0.597)
	29-39	10	15	25 (8.8)	20	5	
	40-49	13	41	54 (18.9)	45	9	
	50-60	21	59	80 (28.1)	70	10	
	60+	37	83	120 (42.1)	108	12	
Education attained	Non-formal	21	49	70 (24.8)	62	8	2.07 (0.725)
	Primary	18	18	66 (23.4)	55	11	
	JHS / MSLC	42	42	130 (46.1)	113	17	
	SHS/Tech./Voc.	1	14	15 (5.3)	14	1	
	Tertially	1	3	1 (0.35)	4	0	
Demographic Status	Indigene	17	59	206 (72.3)	178	28	0.603 (0.74)
	Migrant	64	142	76 (26.7)	67	9	
	Transient	2	1	3 (1.1)	3	0	
Marital status	Single	56	142	10 (3.5)	8	2	5.324 (0.256)
	Married	2	8	198 (69.5)	173	25	
	Divorded	8	14	22 (7.7)	22	0	
	Separated	0	8	8 (2.8)	7	1	
	Widowed	17	30	47 (16.5)	38	9	

* JHS=Junior High School; SHS= Senior High School; MSLC = Middle School Leaving Certificate; Voc. = Vocational

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Table 2 Farm Information in Offinso Municipality and Adansi North District

Characteristics		Districts: Offinso	Districts: Adansi	Total Count	Wildfire incidence in farm area: Yes	Wildfire incidence in farm area: No	Chi-square (p-value)
Gender	Male	45	112	157 (55.1)	138	19	0.24 (0.624)
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* JHS=Junior High School; SHS= Senior High School; MSLC = Middle School leaving certificate; Voc. = Vocational

B. Climate Variability and Trends

Time-series analysis revealed clear climatic shifts over the 20-year period. Mean annual temperature increased by approximately 0.6°C per decade, while annual rainfall declined by 50–70 mm per decade. Relative humidity showed a downward trend, especially during the harmattan season, while wind speeds increased marginally (Table 3).

Table 3 Climate Trends in Adansi North and Offinso (2000–2020)

Climate Variable	Adansi North Districtt	Offinso Municipal	Overall trend
Mean temperature (°C)	26.1-27.0	27.2-28.1	+0.6°C/decade
Rainfall (mm/year)	1480 – 1400	1320 – 1240	-50 to -70 mm/decade
Relative humidity (%)	75 – 70	70 - 65	Declining
Wind speed (m/s)	1.8 - 2.0	2.0 - 2.2	Slight increase

C. Fire Frequency and Spatial Patterns

MODIS data and fire service records indicated recurrent wildfire activity across both districts, with Offinso recording more persistent and spatially clustered hotspots. Fire activity peaked between January and March, with minor events in November and December. Statistical analysis revealed a positive correlation between temperature and wildfire frequency ($r = 0.72$, $p < 0.05$) and a negative correlation between rainfall and fire incidence ($r = -0.68$, $p < 0.05$). Farmers in Offinso reported more frequent and severe fire events than those in Adansi North (Fig. 2 and 3).

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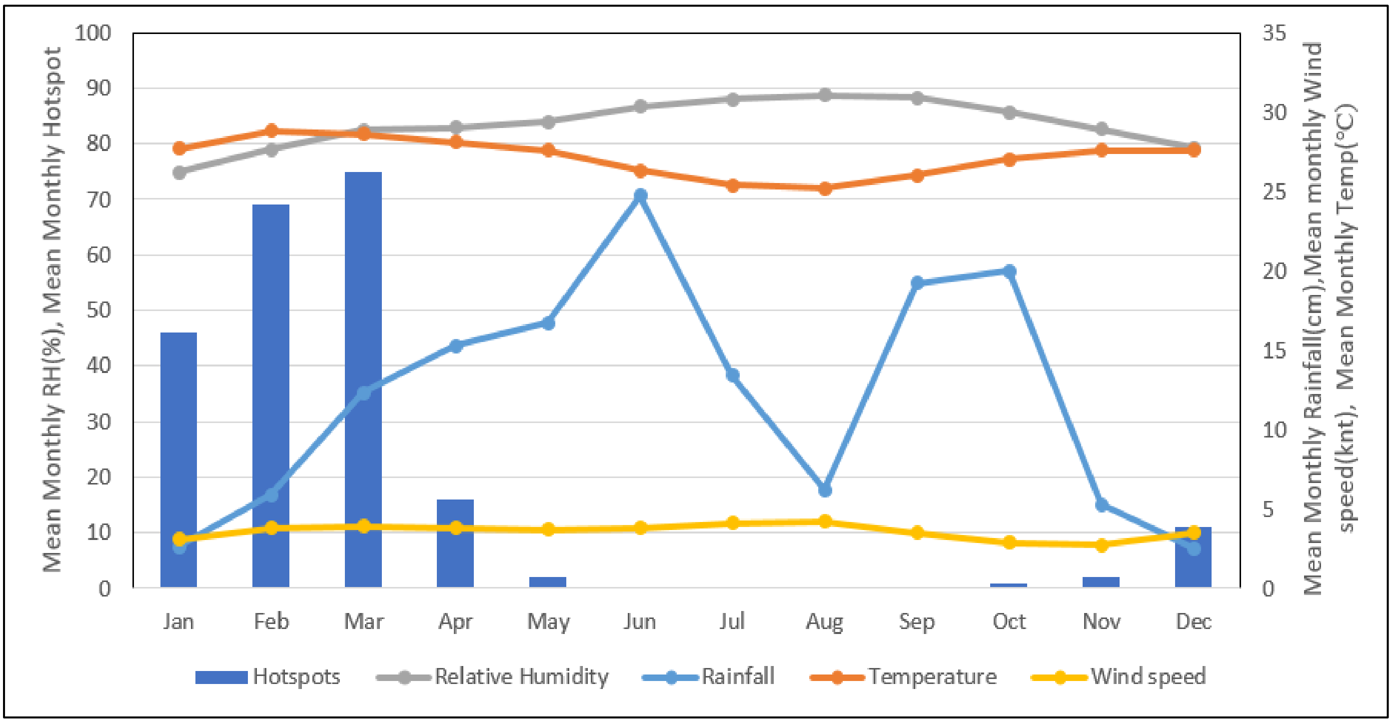

Fig 2 Monthly Distribution of Fire with Mean Monthly Rainfall and Mean Monthly Temperature in the Offinso Municipal from 2000 to 2020.

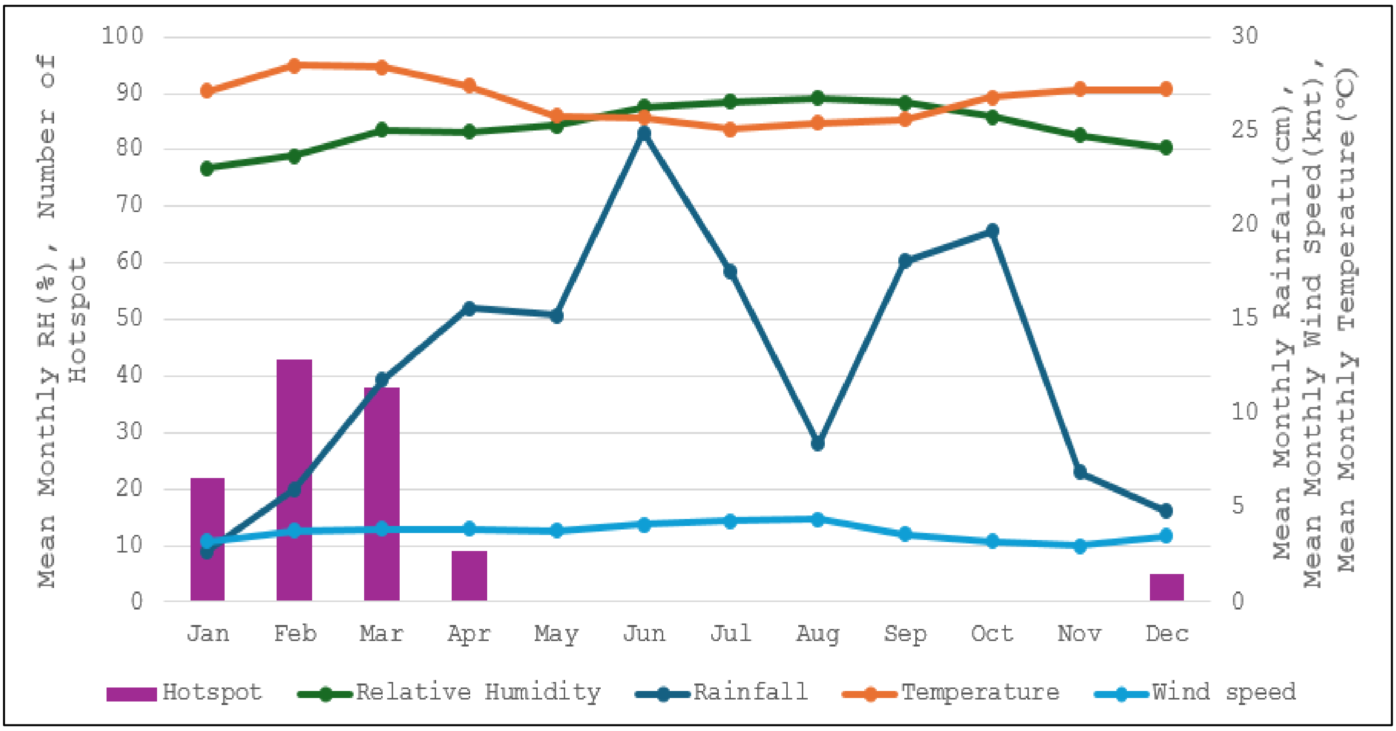

Fig 3 Monthly Distribution of Fire with Mean Monthly Rainfall and Mean Monthly Temperature in the Adansi North District from 2000 to 2020.

D. Drivers of Wildfire

Socio-economic factors were regarded by the majority of respondents as the primary cause causing wildfires (95.8%), followed by environmental factors (69.2%), variables based on the kind of plant (33.7%), and cultural factors (12.61%). The respondents' rankings of the drivers in each district were examined for an acceptable degree of agreement using the Kendall's coefficient of concordance. The opinions of the respondents agreed statistically (Kendall's W = 0.8, p = 0.040). The responders were reasonably, but not overwhelmingly, in agreement with one another. The average rankings further demonstrated that the primary determinant in each of the ecological zones was socioeconomic considerations (Fig. 4).

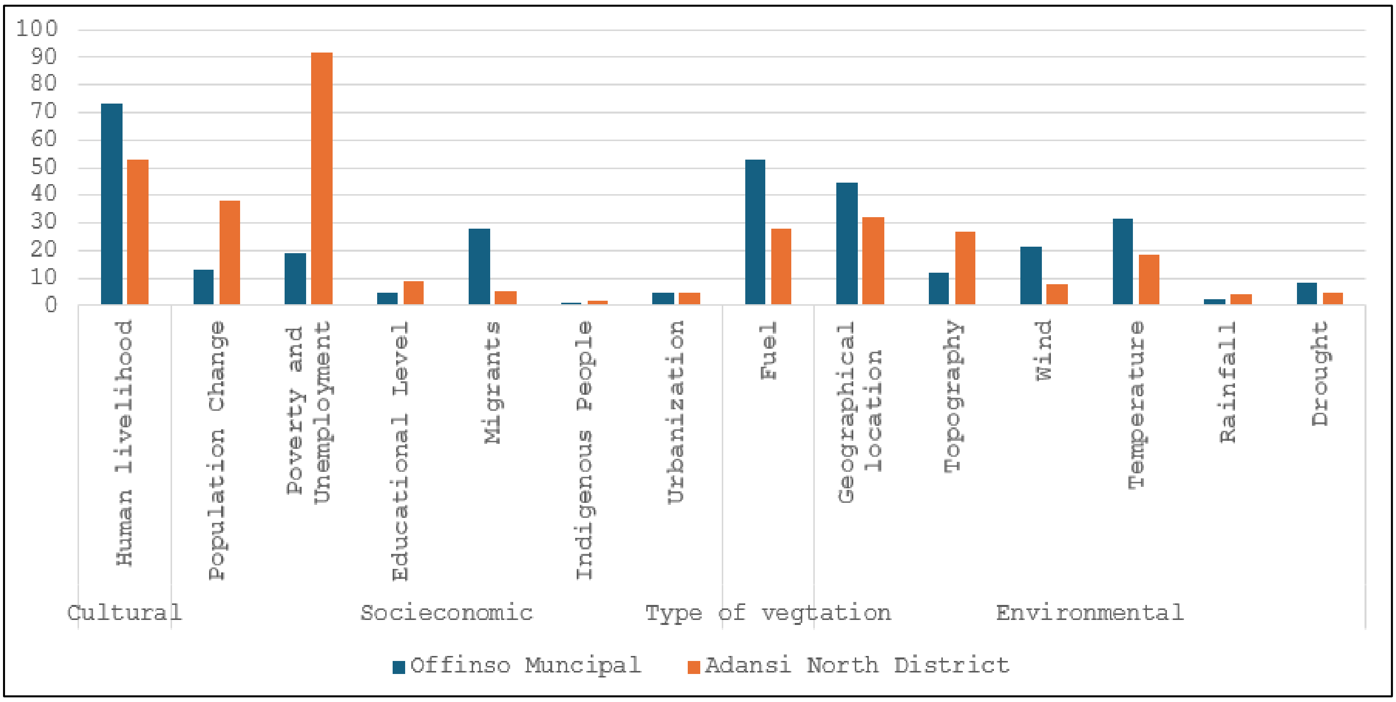

Fig 4 Influencing Variable of Wildfire Incidence in the Offinso Municipality and Adansi North Districts.

Farmers' responses from the study showed that the primary causes of wildfires were attributed to human activities (88%), non-activity (10%), and other factors (2%). Wildfires mostly caused by human activities were hunting (X^2 = 23.5, p < 0.0005), cooking on farms (X^2 = 21.3, p < 0.0005), negligence (X^2 = 25.3, p < 0.0001), smoking (X^2 = 42.1, p < 0.0001), and establishing agricultural plots (X^2 = 4.6, p = 0.200) with hunting, on-farm cooking and smoking recorded highest responses. Non-activity fires were caused by arson (X^2 = 88.6, p < 0.0001) and carelessness (X^2 = 26.5, p < 0.0004). In terms of non-activity-caused fires, arson was widely known in the Dry Semi-deciduous zone. Other human-caused wildfires (X^2 = 2.6, p = 0.47), and unknown reasons (X^2 = 9.9, p = 0.021) were the least. The investigation revealed no substantial differences between the two ecological zones in terms of wildfire sources, except for fire caused by agricultural plot establishment and crop residue burning (Fig. 5).

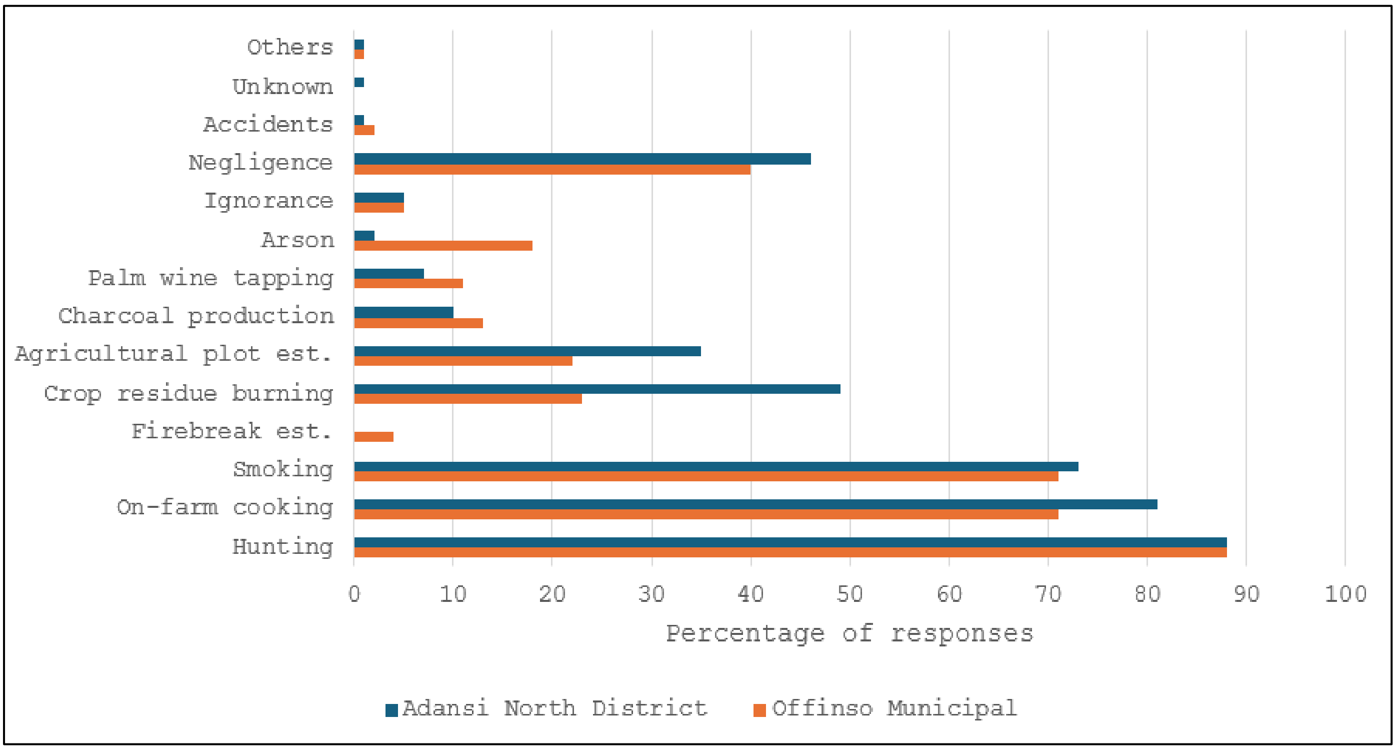

Fig 5 Direct Causes of Wildfire in the Offinso Municipality and Adansi North District.

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E. Farmers' Perceptions and Indigenous Responses

Over 80% of farmers perceived increasing temperatures and longer dry seasons, consistent with meteorological trends. Many attributed heightened fire risk to drier vegetation and declining rainfall. Farmers also observed changes in fire behavior, including faster spread and greater intensity. Farmers took precautions to lessen the risks of wildfires and their effects on the surrounding area. The study area's farmers have created techniques to prevent wildfires. The study revealed that majority of farmers (60.5%) build physical barriers around their farms in dry season to stop fire outbreaks. Ten percent of respondents said that their communities ban the use of fire for hunting during the dry season, while other farmers (12.9%) maintained that monitoring of fire-prone areas by voluntary groups during dry season is their strategy to combat wildfires in their communities. Additionally, some interviewees ((8.1%) said that planting more shade trees in their farms help reduce heat and maintain moisture to prevent fire in their farms. Increasing community awareness and strategies to prevent and control wildfire during dry season (8.5%) was one of the effective ways to prevent and stop wildfires in some communities (Table 4).

Table 4 Indigenous Wildfire Management Strategies

Strategy	Description	Adoption Rate (%)
Firebreaks	Building physical barriers around farm in dry season to stop fire	60.5
Community Patrols	Monitoring of fire-prone areas by volunteer groups during dry season	12.9
Ban on hunting	Enforcement of community rules against use of fire for hunting during dry season	10
Tree planting	Planting more shade trees by farers to reduce heat and maintain moisture in farms	8.1
Education campaigns	Local awareness creation and sensitization on fire outbreak during dry season	8.5

IV. DISCUSSION

The results demonstrate that climate change and human activities are synergistically increasing wildfire risk in Ghana's semi-deciduous forest zones. The rise in temperature and decline in rainfall observed between 2000 and 2020 reflect broader climatic trends in West Africa, consistent with findings by Dwomoh et al. (2019), Agyemang et al. (2015) and Shen et al. (2025). The strong correlation between climate variables and wildfire frequency underscores the sensitivity of cocoa agroforests to climatic fluctuations. The greater vulnerability of Offinso Municipal compared to Adansi North supports the hypothesis that drier ecosystems are more fire-prone to wildfires due to lower fuel moisture, distance from water bodies, longer dry seasons, human settlements and deforestation. This finding supports Wimberly's (2024) and Husseini's (2020) argument that deforestation and climate change are some of the main drivers of forests fires in African tropical forests. This finding again aligns with fire ecology theories (Oddi, 2018) and Niyogi (2025) that distance and steepness of slopes from water bodies, human settlements and coverage of aquatic bodies greatly influenced fire vulnerability. Hunting, agricultural activities, on-farm cooking and smoking as major ignition sources recorded from the study is in line with research by Amissah et (2010) where burning of slashed weeds on crop lands, improper fire control strategies, human settlements, lack of education and sensitization of communities on wildfire in dry season were highlighted as some of the causes of wildfires in local communities. Lack of enforcement of fire regulations or policies, lack of firefighting equipment at community levels as some of the problems associated with wildfire control in the study agrees with findings of Husseini (2020) and Naawa et al. (2024) that lack of policy and regulatory strategies and use of technology make fire control difficult at community levels.

Farmers' perceptions of climate variability in the study largely corresponded with scientific observations, demonstrating the value of local knowledge in environmental monitoring. However, indigenous strategies such as formation of fire patrol voluntary groups and placing ban on use of fire for hunting in dry season reflect local adaptive learning inclusivity and social cohesion strategy for community participation and development as reported in South Africa by Aigbe (2025) and Platt et al. (2015). Limited resources and lack of formal institutional support, firefighting equipment and incentives discourage community participation as reported in research by Naawa (2024). Integrating the traditional approaches into formal community-based fire management programs enhanced effective wildfire prevention in the local communities but these have significant implications for policy makers especially in Ghana's wildfire management framework, established in the early 2000 but remains under-resourced and fragmented. It was realized in the study that if climate-smart agricultural policies are integrated into wildfire risk assessment, particularly in cocoa-growing landscapes as reported in research by Chicas (2023) and Naawa et al. (2024), it will help farmers in fire prevention in the two agro-ecological zones in Adansi North District and Offinso Municipality of Ghana. Furthermore, promoting agroforestry systems by planting more trees in cocoa farms can improve moisture levels and reduce fire spread while enhancing microclimate stability and biodiversity (Lindenmayer et al., 2014; Addo-Fordjour, 2017; Lecina-Diaz, 2023). The study also emphasizes the need for continuous capacity building, fire education, and enforcement of ban on use of fire for hunting in dry season.

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V. CONCLUSIONS AND RECOMMENDATIONS

Wildfires in Ghana's cocoa agroforests are intensifying because of the combined effects of climate change and human activity. Findings from the study revealed that rising temperatures, declining rainfall, and extended dry periods were the main primary climatic drivers of wildfire occurrence in the two ecological zones of Ghana. Human activities particularly hunting, on-farm cooking and smoking are the major ignition sources, while indigenous adaptive practices remain essential but under-supported. Strengthening community-based fire management strategies will formalize, encourage and resource voluntary local wildfire patrol teams in wildfire prevention in communities. Community collaboration with farmers, forestry services, district assemblies and Ghana National Fire Service (GNFS) will help prevent wildfire occurrences in the districts and to promote climate-smart agriculture by tree planting more trees with their crops. This systems will reduce temperature, improve farm moisture levels and enhance landscape resilience in the districts. Capacity building and education will increase awareness or campaign on safe wildfire prevention and adaptation strategies in the districts. Long-term monitoring and establishment of climate–fire observatories across ecological zones will help track wildfire hotspots and wildfire indicators across the ecological zones.

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