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Microclimate Patterns and Their Impacts on Maize Production in Gwagwalada Area Council, Federal Capital Territory, Nigeria

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Abstract-* Microclimatic variability, expressed principally through fluctuations in rainfall and temperature, constitutes one of the most decisive determinants of crop performance in rain-fed farming systems across sub-Saharan Africa. This paper examines the pattern of microclimatic elements and their impacts on maize (Zea mays) production in Gwagwalada Area Council of the Federal Capital Territory (FCT), Nigeria, drawing on a thirty-year climatic record (1990 to 2020) complemented by household survey data obtained from two hundred and seventy-six respondents drawn from the upper, middle and lower agro-ecological zones of the study area, represented respectively by Ibwa, Gwako and Gwagwalada Central. A mixed-methods design combining polynomial trend regression of meteorological data with structured questionnaires, key informant interviews and Pearson product-moment correlation analysis was adopted. Findings show that annual rainfall in the area followed an erratic and weakly predictive trend (R2 = 0.15), with a general decline reported by seventy-three per cent of farmers, while annual mean temperature exhibited a stronger and more coherent warming signal (R2 = 0.61), rising markedly from the early 2000s onward. Seasonal analysis revealed that the June-July-August-September (JJAS) rainfall, which coincides with the reproductive stage of maize, was the variable most strongly correlated with maize yield in the upper zone (r = 0.66), while regression modelling showed that area cultivated and March-April-May maximum temperature were the most significant predictors of yield (R2 = 0.88). Increasing temperatures were associated with poor germination, wilting, delayed flowering and tasselling, and elevated pest incidence, while erratic rainfall onset disrupted planting calendars and depressed yields substantially below the varietal optimum. The paper concludes that microclimatic change is measurably reshaping the agronomic calendar and yield potential of maize in Gwagwalada Area Council and recommends strengthened climate monitoring, timely dissemination of seasonal forecasts and support for climate-responsive agronomic planning.

***Keywords:* Microclimate, Rainfall Variability, Temperature Trend, Maize Production, Gwagwalada, Federal Capital Territory**

I. INTRODUCTION

Agriculture remains one of the most climate-dependent sectors of the global economy, as the growth, development and productivity of crops are intimately linked to prevailing atmospheric conditions (IPCC, 2022). Variations in temperature, rainfall, relative humidity, solar radiation and wind speed constitute the principal micro-climatic elements that shape crop performance within specific local environments, influencing critical physiological processes such as photosynthesis, transpiration, germination and nutrient uptake (Lobell, Schlenker and Costa-Roberts, 2011). Among the major food crops cultivated worldwide, maize occupies a prominent position on account of its extensive cultivation and its significance as a staple food, livestock feed and industrial raw material (FAO, 2023). Even modest shifts in micro-climatic conditions may translate into substantial variation in maize yield across major producing regions (Ray, Mueller, West and Foley, 2019), and rising temperatures combined with irregular precipitation increasingly threaten cereal production worldwide, particularly where agriculture depends heavily on rainfall rather than irrigation (Zhao et al., 2021).

Within the African continent, the relationship between micro-climatic elements and crop productivity assumes even greater significance because agricultural systems on the continent depend overwhelmingly on natural climatic conditions rather than controlled irrigation. Agricultural projections indicate that maize yields across several parts of sub-

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Saharan Africa may decline appreciably unless adaptive agricultural practices are strengthened in response to changing climatic conditions (Serdeczny et al., 2020). In Nigeria, maize occupies a prominent position among cultivated crops on account of its adaptability across ecological zones, and Nigerian farmers cultivate the crop widely across the Guinea savannah, Sudan savannah and derived savannah zones where climatic conditions generally favour cereal production (Ayanlade and Radeny, 2020). Nevertheless, variations in rainfall onset, temperature intensity and humidity levels frequently affect planting schedules, crop growth and harvest outcomes across the country (Federal Ministry of Agriculture and Rural Development, 2022).

Within the Federal Capital Territory (FCT), agriculture continues to serve as an important economic activity for rural households, particularly within the area councils where farming constitutes a primary means of livelihood. The ecological setting of the FCT falls within the Guinea savannah zone and experiences a tropical wet and dry climate characterised by distinct rainy and dry seasons (Federal Capital Territory Agricultural Development Programme, 2022). Gwagwalada Area Council represents one of the major agricultural zones within the FCT where maize cultivation forms an important component of local farming systems, yet agricultural productivity in the area increasingly faces challenges associated with variations in rainfall timing, temperature intensity and humidity fluctuations, which influence germination, growth duration, pest occurrence and grain formation (Federal Capital Territory Agricultural Development Programme, 2022). Despite the significance of maize farming in the area, limited empirical research has systematically examined how localised micro-climatic conditions influence maize productivity within Gwagwalada Area Council. This paper addresses this gap by determining the microclimate patterns prevailing in the area and assessing their impacts on maize production, generating evidence intended to support improved agricultural planning and climate adaptation within the Territory. The aim of this paper is to assess the pattern of microclimatic elements and their impacts on maize production in Gwagwalada Area Council, FCT, Nigeria. The specific objectives are to determine the microclimate patterns in Gwagwalada Area Council, FCT, Nigeria; and assess the impacts of microclimatic elements, namely temperature and rainfall, on maize production in the study area. Climatic variability remains the principal source of fluctuation in food production across the developing world, and microclimatic elements such as rainfall variability pose a direct threat to maize production, which constitutes a staple food in Nigeria. Considerable research has examined the effects of weather and climate on agricultural production generally, but comparatively few studies have focused specifically on the effects of microclimate on maize production within the Federal Capital Territory. The findings of this paper contribute to the pool of knowledge that is vital to government agencies, extension officers and future scholars, and inform environmental planners and agriculturalists engaged in the management of agricultural resources within the Territory.

II. THE STUDY AREA

Gwagwalada Area Council is located approximately fifty-five kilometres from the Federal Capital City of Nigeria, within the Federal Capital Territory. The Council lies between latitude 08°55'N and 09°00'N and longitude 07°00'E and 07°05'E, with a total landmass of about 6,500 hectares (Balogun, 2001). The climate of the Territory is of the hot, humid tropical type, transitional between the climatic regimes of the southern and northern parts of the country, with mean temperatures ranging from 30°C to 40°C (NIMET, 2008). Total annual rainfall averages approximately 1,650 millimetres, of which sixty per cent falls during July, August and September, while relative humidity rises above fifty per cent during the rainy season but falls to as low as twenty per cent during the dry season (Hassan, 2008; Ishaya, 2013). River Usuma, a tributary of the River Gurara, is the principal river draining the area, and farmers in the flood plains downstream of Gwagwalada town use its waters directly for dry-season irrigation.

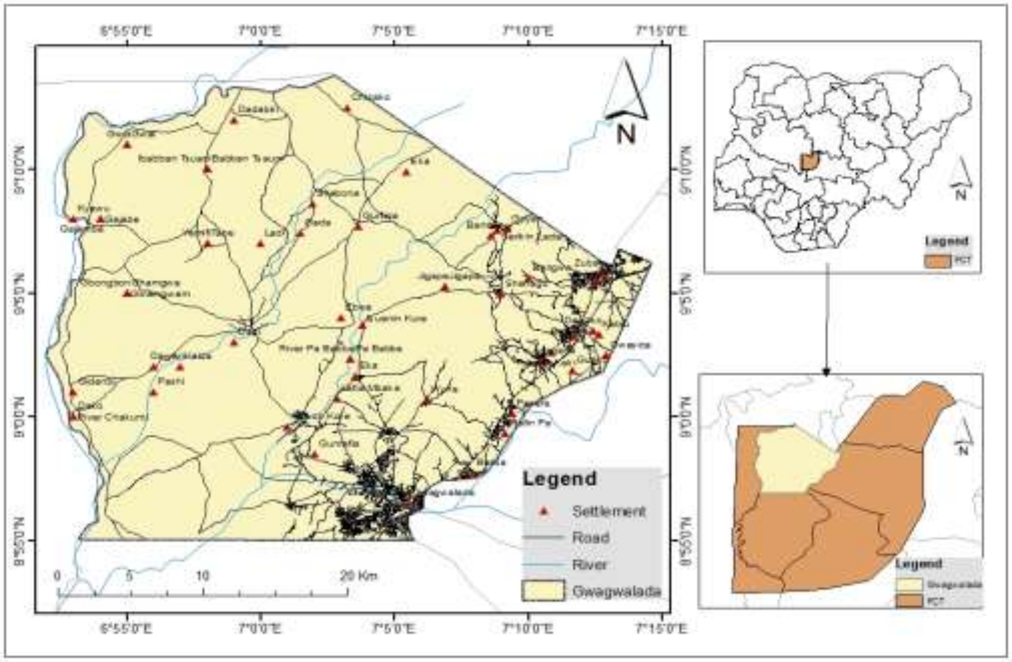

Figure 1: Map of Gwagwalada Area Council Showing Settlements, Roads and Rivers

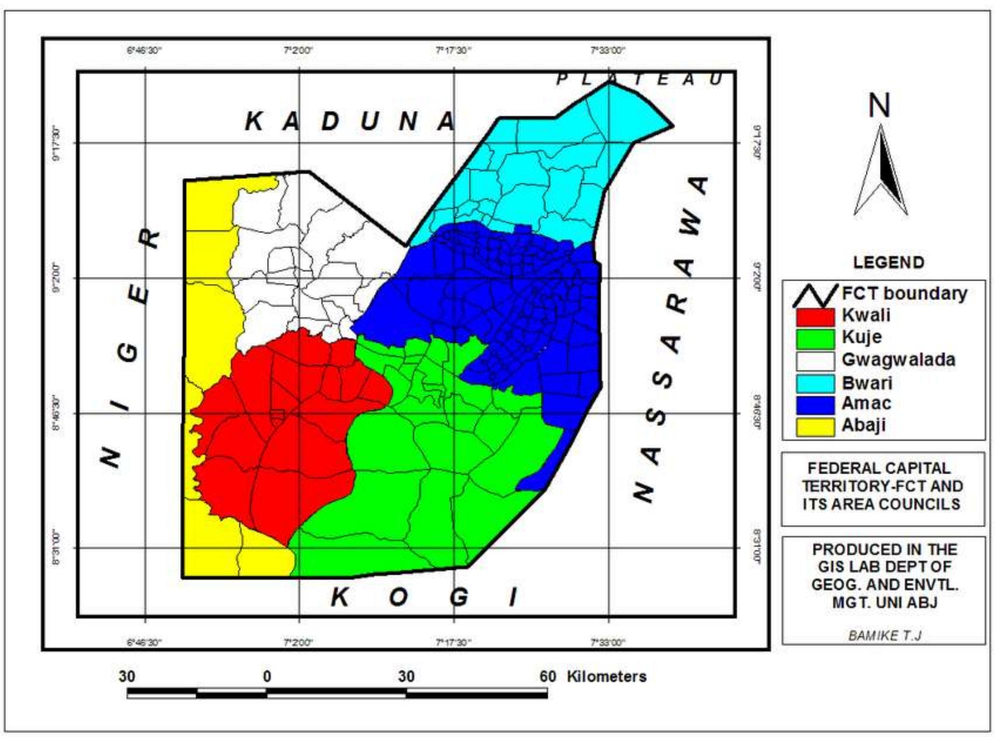

Figure 2: Administrative Map of the Federal Capital Territory Showing Gwagwalada Area Council

For the purpose of analysis, the Area Council was stratified into three agro-ecological zones on the basis of maize production potential: an upper zone comprising Paiko, Ibwa and Ikwa with high maize production potential; a middle zone comprising Dobi, Gwako, Tunga Maje and Zuba representing a transitional potential; and a lower zone comprising Gwagwalada Central, Kutunku and Staff Quarters with comparatively lower potential. Ibwa, Gwako and Gwagwalada Central were purposively selected to represent the upper, middle and lower zones respectively.

III. LITERATURE REVIEW

3.1 The Concept of Microclimate

Microclimate refers to the climatic condition prevailing in local areas near the surface of the earth, encompassing environmental variables such as temperature, humidity, wind speed and light, which together provide meaningful parameters for ecological activity and habitat selection (Naiman et al., 2005). Microclimate is distinguished from macroclimate, the homogenous air mass overlying the ground, by the fact that it is modified by terrestrial properties, whether bare ground or vegetated surfaces (Rosenberg et al., 1983). Every microclimate is a complex system of variables, including radiation, air temperature, surface temperature, humidity, wind and carbon dioxide concentration, that jointly shape the growing environment of crops such as maize (Behera et al., 2012; Jones, 1993).

3.2 Impact of Microclimate on Agriculture and Maize Production

The response of crop yield to climate varies widely depending on species, cultivar, soil condition and other local factors. In the tropics, where dryland agriculture predominates and some crops already operate close to their maximum temperature tolerance, yield tends to decrease with even minimal increases in temperature, an effect that becomes more pronounced where rainfall also declines (Parry, 1990). Water availability during the flowering stage of maize, comprising tasselling, silking and pollination, is particularly critical: while the crop tolerates moisture deficit reasonably well during the vegetative and ripening stages, the greatest decline in grain yield occurs when water deficit coincides with the flowering period, since this reduces the number of grains formed per cob (Madiyazhagan, Birch, Carberry and Michael, 2004). Rainfall trends generally show significant variation in spatial and temporal patterns of both total annual and seasonal rainfall, which affects crop production, including maize, given its heavy dependence on rainfall (Oseni and Masarirambi, 2011).

Temperature exerts a further, distinct influence on maize physiology. Increasing temperature raises atmospheric evaporative demand and therefore competition for available soil water, while also accelerating the mineralisation of soil organic matter, with consequent reduction in soil fertility and structure (Nyabundi and Njoka, 1991). Elevated temperature further favours the development of pests and diseases, compounding agricultural losses, while post-harvest spoilage tends to increase where high temperature coincides with high atmospheric humidity. At the continental scale, the IPCC (2001) reported that regional increases in temperature had already produced discernible effects on a diverse set of physical and biological systems, a pattern corroborated for Nigeria by evidence of a mean annual temperature increase of about one degree Celsius since 1960, at an average rate of 0.21°C per decade, with the most rapid warming recorded in the March-April-May season (RoK, 2012).

3.3 Empirical Studies on Climate Variability and Maize Yield

A growing body of empirical work links climate variability directly to maize productivity across Africa. Ray, Mueller, West and Foley (2019) demonstrated that climate variation explains approximately one-third of observed global crop yield variability, underscoring the centrality of climatic factors relative to management and genetic factors. Waha, Müller and Rolinski (2013) similarly established that projected climate change carries substantial implications for maize yield across sub-Saharan Africa, while more recent studies in West Africa have confirmed that rainfall, temperature and relative humidity jointly and significantly influence maize yield outcomes (Dwamena, 2022; Nzali,

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2024). Within Nigeria specifically, Ideki, Nwaerema and Abali (2024) found a measurable effect of climate variability on crop yield between 1980 and 2020, while Kolapo (2025) demonstrated that climate-smart agricultural practices meaningfully improve outcomes for maize farming households confronted with variable weather. These findings collectively situate the present study within an established and expanding literature confirming the sensitivity of maize, as a rainfall-dependent cereal, to fluctuations in microclimatic conditions.

IV. THEORETICAL FRAMEWORK

4.1 Environmental Determinism Theory

This paper is anchored on the Environmental Determinism Theory, associated with Semple (1911), which holds that the physical environment, including climatic conditions, exerts a dominant influence on human activity and productivity. Applied to agriculture, the theory suggests that the natural pattern of rainfall and temperature within a locality substantially conditions the character, timing and productivity of farming activity, such that farmers' agronomic decisions, including planting dates and choice of variety, are shaped in large measure by the prevailing microclimatic regime. While the theory has been critiqued for understating human agency and adaptive capacity, it remains analytically useful for explaining why, in a predominantly rain-fed farming system such as that of Gwagwalada Area Council, variation in rainfall and temperature translates directly into variation in maize performance.

4.2 Agro-Ecological Systems Theory

The paper is further informed by the Agro-Ecological Systems Theory, which conceptualises farming as a dynamic interaction between biophysical elements, including climate, soil and vegetation, and the management practices of farmers (Altieri, 1995). This framework recognises that maize production in Gwagwalada does not respond to microclimatic elements in isolation but through the interaction of rainfall and temperature with cultivar choice, planting date, soil condition and input use, an interaction that this paper examines empirically in the analysis of correlation and regression between weather elements and maize yield.

V. METHODOLOGY

The paper adopted a mixed-methods research design combining quantitative analysis of thirty years (1990-2020) of rainfall and temperature data obtained from the Nigerian Meteorological Agency and National Centers for Environmental Prediction (NCEP) reanalysis, with a household survey administered to farmers in the study area. The target population comprised households cultivating maize within Gwagwalada Area Council. Using the Krejcie and Morgan (1970) formula for sample size determination, a stratified multistage sampling procedure was applied, with the Area Council divided into upper, middle and lower agro-ecological zones represented respectively by Ibwa, Gwako and Gwagwalada Central. A total of two hundred and seventy-six households were interviewed, comprising one hundred and twenty-three respondents in Ibwa, one hundred and one in Gwako and fifty-two in Gwagwalada Central, in addition to key informant interviews with ten agricultural officers of the Federal Capital Development Authority.

Climatic data on annual and seasonal rainfall and temperature, together with data on area under maize cultivation and yield per hectare, were analysed in Microsoft Excel to generate polynomial trend lines and the coefficient of determination (R2), following Best and Kahn (1998). Data obtained from household questionnaires were coded and analysed in SPSS using descriptive frequencies and percentages, while Pearson product-moment correlation and multiple regression analysis were used to examine the statistical relationship between maize yield and the weather elements of annual, seasonal, minimum and maximum rainfall and temperature. Qualitative information from interviews with agricultural officers was analysed thematically to contextualise the quantitative findings.

VI. RESULTS AND DISCUSSION

6.1 Microclimate Patterns in Gwagwalada Area Council

6.1.1 Rainfall Trend

Analysis of the general annual rainfall trend in Gwagwalada Area Council revealed an erratic pattern, with the polynomial regression model yielding a coefficient of determination (R2) of 0.15, indicating a weak predictive power and confirming the absence of a clear, consistent direction in rainfall over the study period. Three extreme flooding events, recorded in 2003, 2006 and 2020, further attest to the erratic character of rainfall in the area.

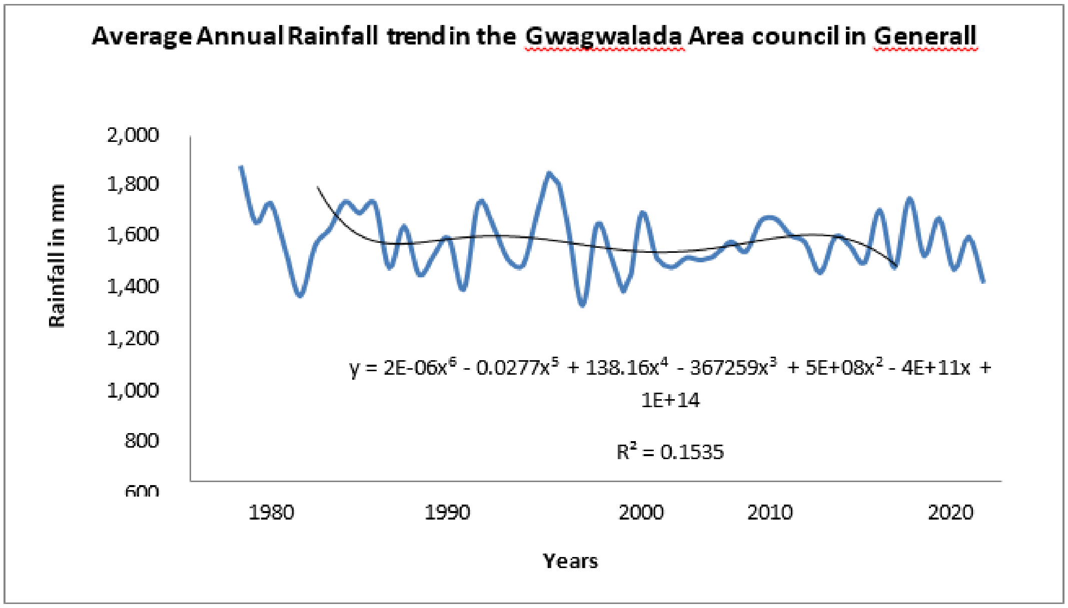

Figure 3: Average Annual Rainfall Trend of Gwagwalada Area Council, 1990-2020

Zonal disaggregation revealed contrasting patterns. In the upper zone (Ibwa), annual rainfall increased slightly at a rate of 3.9 millimetres per annum, driven principally by a marked rise in October-November-December (OND) rainfall of 4.05 millimetres per annum, even as the March-April-May (MAM) season showed a decline of 1.32 millimetres per annum. In the middle zone (Gwako), annual rainfall declined at a rate of 2.87 millimetres per annum, with the MAM, June-July-August-September (JJAS) and OND seasons all recording modest decreases. In the lower zone (Gwagwalada Central), the annual trend was nearly flat, with a negligible decline of 0.04 millimetres per annum, masking a significant decrease in MAM rainfall (2.95 millimetres per annum) alongside increases in both the JJAS (2.03 millimetres per annum) and OND (3.16 millimetres per annum) seasons. These findings corroborate the observation of Andressen et al. (2008) that no homogenous trend characterises precipitation change across a given region, and align with the Republic of Kenya (2012) finding of a measurable long-term decline in rainfall across comparable agro-ecological settings.

Farmers' perceptions strongly corroborated the instrumental record. Seventy-three per cent of all respondents reported a decrease in rainfall, with the perception strongest in the upper zone (thirty-six per cent of total respondents) and weakest in the lower zone (thirteen per cent), a pattern consistent with the instrumental finding of declining rainfall in Ibwa against relative stability in Gwagwalada Central. When asked to characterise the nature of change observed, fifty-seven per cent of respondents in Gwagwalada Central, thirty-three per cent in Gwako and sixteen per cent in Ibwa reported a delayed onset of the rains, while thirty-five per cent in Ibwa and twenty-eight per cent in Gwako reported a lighter density of rainfall. Eighteen per cent of respondents in Ibwa additionally reported that rainfall had become unpredictable in its distribution.

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Table 1: Farmers' Perception of Rainfall Trends Across the Study Zones

Observed Change	Ibwa (%)	Gwako (%)	G/Lada (%)	Overall (%)
Increase in precipitation	3	1	1	5
Decrease in precipitation	36	24	13	73
Delayed onset of rains	5	6	1	12
Increased frequency of droughts	1	1	1	3
No change / uncertain	0	1	1	3

6.1.2 Temperature Trend

The temperature series presented a markedly stronger and more coherent trend than rainfall. Polynomial regression modelling of annual mean temperature yielded an R2 of 0.61, indicating that the model explained approximately sixty-one per cent of the variation in temperature over time, a substantially higher predictive power than obtained for rainfall. Temperature initially declined between 1980 and 2000, before reversing into a sustained upward trend from 2000 to 2020, warming at an annual rate of approximately 0.027°C, consistent with the IPCC (2018) special report on global warming of 1.5 degrees Celsius.

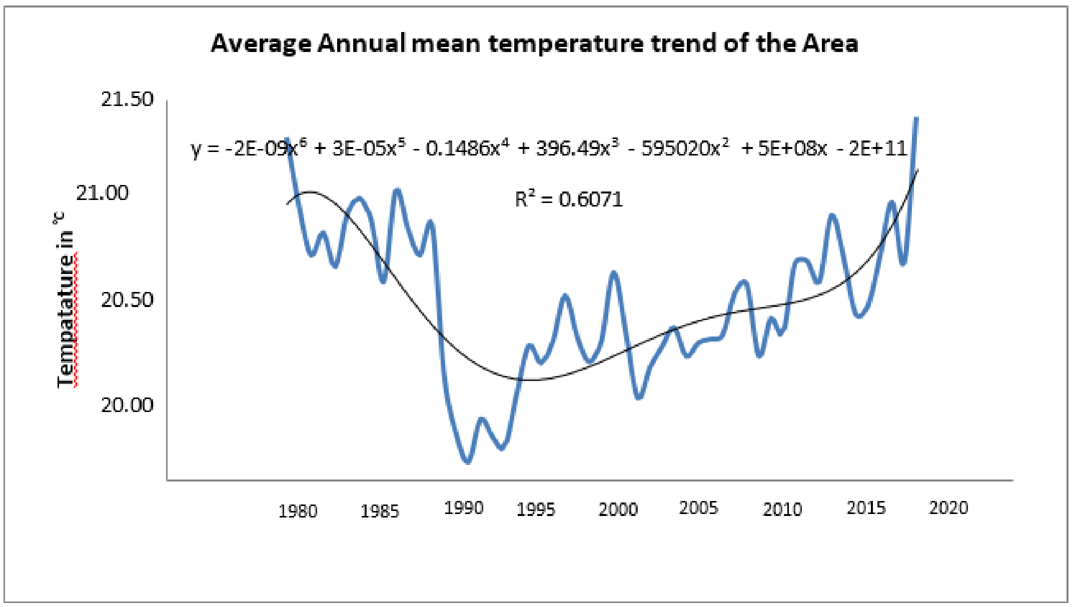

Figure 4: Average Annual Mean Temperature Trend of Gwagwalada Area Council, 1980-2020

Zonal analysis of maximum and minimum temperature confirmed the general warming signal across all three zones. In the upper zone, minimum temperature rose at 0.018°C per annum and maximum temperature at 0.033°C per annum; in the middle zone, the corresponding rates were 0.02°C and 0.037°C per annum; and in the lower zone, 0.022°C and 0.01°C per annum respectively. Independent-samples t-tests comparing minimum and maximum temperature across the three zones returned statistically significant differences ($p < 0.001$ in all comparisons), confirming that the warming trend, while common to all zones, differs significantly in intensity from one zone to another. Over eighty per cent of surveyed farmers reported having noticed a long-term shift in temperature, with 85.1 per cent specifically reporting an increase, a perception most pronounced for the OND season, where eighty-seven per cent of respondents in Gwako and eighty-six per cent in Gwagwalada Central reported rising temperatures.

6.2 Impacts of Microclimatic Elements on Maize Production

The area under maize cultivation in Gwagwalada Area Council followed a polynomial trend with a comparatively high R2 of 0.80, rising steadily from 1980 to about 1999, declining sharply thereafter to about 2010 in a period coinciding with declining annual rainfall, before recovering and expanding markedly toward 2020.

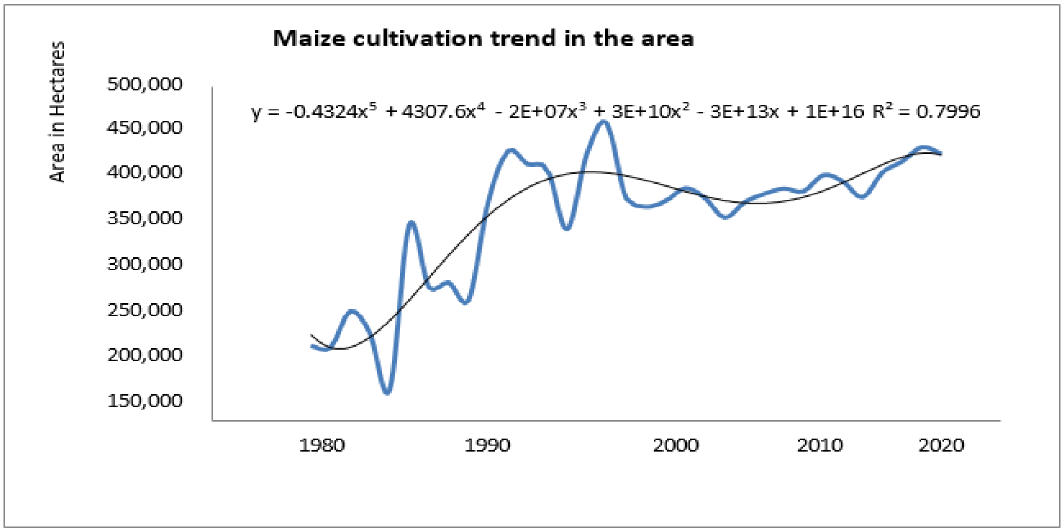

Figure 5: Trend in Area Under Maize Cultivation in Gwagwalada Area Council, 1980-2020 (Hectares)

Analysis of the relationship between rainfall and maize yield (R2 = 0.53) indicated a fair predictive relationship, moderated by considerable seasonal variability. A delayed onset of rainfall, reported by more than half of respondents in the lower zone, directly disrupted planting calendars: farmers who planted in anticipation of early rains that failed to materialise experienced poor germination, reported by seventy-seven per cent of respondents in Ibwa, while an eighteen per cent share of Ibwa farmers who experienced unpredictable rainfall distribution recorded uneven germination and consequently reduced plant population per unit area. Conversely, increased rainfall during the October-November harvest period, associated with the observed rise in OND rainfall, promoted maize rot, reported by seventy-seven per cent of respondents in Ibwa and sixty-five per cent in Gwako, on account of poor drying and storage conditions before the crop reached recommended moisture content.

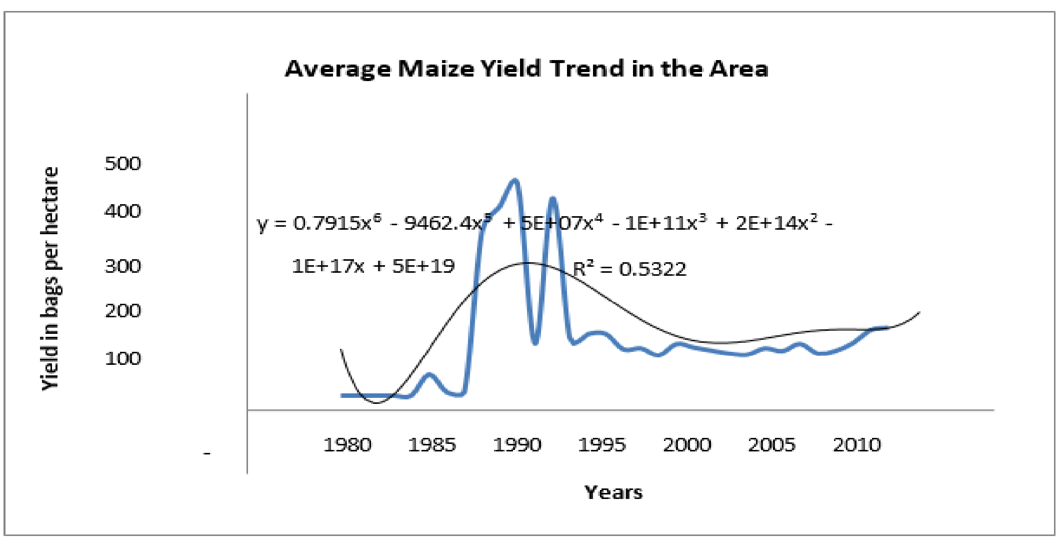

Figure 6: Rainfall and Maize Yield Trend in Gwagwalada Area Council Over the Study Period

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Increasing temperature exerted equally consequential, though seasonally differentiated, effects. During the March-April-May planting and vegetative stage, twenty-nine per cent of respondents in Ibwa and twenty-one per cent in Gwako reported poor germination attributable to rising temperature, while wilting was reported by thirty-two per cent of respondents in Gwako and thirty-three per cent in Gwagwalada Central. During the June-July-August-September reproductive stage, when flowering, pollination and cob formation occur, thirty-three per cent of Ibwa respondents and forty-two per cent of Gwako respondents reported poor flowering and tasselling attributable to elevated temperature, an effect consistent with the physiological finding that high temperature accelerates drying of the silk and thereby impairs pollination and grain number per cob (Madiyazhagan et al., 2004). During the October-November-December harvest season, by contrast, eighty per cent of Ibwa respondents regarded rising temperature as beneficial for drying the harvested crop, whereas fifty per cent of respondents in Gwagwalada Central, where planting occurs later in the season, associated the same warming with reduced yield.

Table 2: Effect of Increasing March-April-May Temperature on Maize Production (Selected Responses)

Observed Effect	Ibwa (%)	Gwako (%)	G/Lada (%)
Poor germination	29	21	11
Wilting	21	32	33
Reduced yield	3	11	33
Good germination	12	21	0
Increased pest infestation	12	11	4

Correlation analysis for the upper zone confirmed that JJAS rainfall was the weather element most strongly associated with maize yield ($r = 0.66$), followed by area cultivated ($r = 0.48$) and annual rainfall ($r = 0.49$), a relationship consistent with the fact that the JJAS season coincides with the reproductive stage of maize, during which yield is most sensitive to moisture availability. The corresponding multiple regression model returned an R2 of 0.88, indicating that the selected climatic and agronomic variables jointly explained approximately eighty-eight per cent of variation in maize yield in the upper zone, with area cultivated and MAM maximum temperature emerging as the most statistically significant predictors ($p < 0.05$).

Table 3: Correlation Coefficients Between Selected Weather Variables and Maize Production, Upper Zone

Variable	Coefficient (r)
Area cultivated	0.475
Annual rainfall	0.489
Annual minimum temperature	0.208
JJAS minimum temperature	0.489
JJAS rainfall	0.659
OND rainfall	-0.230

These results are consistent with the finding of Oseni and Masarirambi (2011) that rainfall trends in comparable agro-ecological settings display significant spatial and temporal variation that translates directly into variability in maize production, and with Ray, Mueller, West and Foley (2019), who established that climate variation accounts for a substantial share of observed global crop yield variability. The evidence from Gwagwalada Area Council further confirms the physiological sensitivity of maize to the timing, rather than merely the total quantity, of both rainfall and temperature exposure across its growth stages.

VII. CONCLUSION

This paper has determined the pattern of microclimatic elements prevailing in Gwagwalada Area Council and assessed their impacts on maize production. The evidence demonstrates that while rainfall in the area follows an erratic, weakly predictable pattern that varies considerably by zone and season, temperature has followed a more coherent and accelerating warming trend, particularly since the early 2000s. Both elements exert measurable and, in several respects, statistically significant effects on maize production, operating principally through their influence on planting timing, germination success, flowering and pollination, pest incidence, and post-harvest drying and storage outcomes. The strength of thmoisture availability during the reproductive stage of the crop. These findings reinforce the broader understanding that microclimatic conditions remain a central determinant of agricultural outcomes within rain-fed farming systems such as that of Gwagwalada Area Council, and that a clear, disaggregated understanding of local climatic patterns is indispensable to effective agricultural planning within the Federal Capital Territory.

VIII. RECOMMENDATIONS

Arising from the findings, the following are recommended:

i. The Nigerian Meteorological Agency and agricultural extension agencies should strengthen climate monitoring systems and improve the timely dissemination of seasonal rainfall and temperature forecasts to farmers in Gwagwalada Area Council, given the demonstrated divergence in rainfall and temperature trends across the upper, middle and lower zones.
ii. Agricultural extension services should assist farmers in aligning planting calendars with the onset and seasonal distribution of rainfall specific to their zone, rather than applying a uniform planting recommendation across the Area Council.
iii. Research institutions should intensify the development and dissemination of maize varieties tolerant of both moisture stress during the reproductive stage and elevated temperature during flowering, given the demonstrated sensitivity of maize yield to JJAS rainfall and MAM maximum temperature.
iv. Post-harvest handling support, including improved drying and storage facilities, should be extended to farmers in the upper and middle zones to reduce the maize rot associated with increased OND rainfall during the harvest period.

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