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Assessment of climate variability on crop productivity and household nutrition security among smallholder farmers

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Abstract
Farmer perspective: a smallholder maize grower near Monrovia summed up seven years of farming in a single observation, that the planting calendar her mother taught her no longer seems to match what the rains actually do, and this research set out to test whether that lived experience matches the region's actual weather record. Combining seven years of secondary rainfall and temperature data with a survey of 210 smallholder farming households, this research assessed relationships between climate variability, crop yield, household dietary diversity, and farmer coping strategies around Monrovia. Annual rainfall varied by as much as 44% between the wettest and driest years recorded, while mean temperature rose by 0.9 °C over the seven-year observation window, and maize yield showed a strong negative correlation with both rainfall variability and temperature anomaly (r = -0.71 and r = -0.64 respectively). Household Dietary Diversity Score tracked this yield variability closely, falling from an average of 6.8 in favorable climate years to 4.9 in the most climate-stressed year recorded. Farmer coping strategies varied considerably in both prevalence and effectiveness, with crop diversification and off-farm income generation associated with smaller dietary diversity declines during stress years than strategies like reducing meal frequency or selling productive assets, which farmers reported using more often as stress intensified but which did little to protect household nutrition in the following season. These findings confirm that climate variability measurably threatens both crop productivity and household nutrition security in this farming population, and point toward proactive coping strategies, diversification and income smoothing specifically, as more protective than the reactive, asset-depleting strategies farmers turn to once a poor season has already arrived.

Keywords: Climate variability, crop productivity, household nutrition security, dietary diversity, coping strategies, smallholder farmers, rainfall variability, temperature anomaly, food availability, climate risk

Introduction

Farmer perspective often anticipates what formal climate data eventually confirms, and a smallholder maize grower near Monrovia describing how her mother's planting calendar no longer seems to match the rains captures, in a single observation, a shift that this research's seven-year rainfall record bears out with considerable statistical clarity. Climate variability, distinct from long-term climate change trends, refers to year-to-year fluctuation in rainfall timing, distribution, and quantity, and temperature, and this variability itself, independent of any longer-term directional trend, can meaningfully disrupt smallholder farming systems that depend on reasonably predictable seasonal patterns for planting, growth, and harvest timing decisions [1, 2].

Crop yield sensitivity to rainfall and temperature variability is well documented across West African smallholder farming systems generally, with maize and other staple cereals showing particular sensitivity to rainfall timing during critical growth stages like flowering and early grain fill, a sensitivity that can produce substantial yield loss even without any change in total seasonal rainfall, simply from shifts in when that rainfall arrives relative to the crop's developmental stage [3, 4].

Household nutrition security, encompassing both food availability and dietary diversity, depends heavily on farm production for many smallholder households, meaning climate-driven yield variability translates fairly directly into nutrition security variability for households without substantial non-farm income or market purchasing power to buffer against a poor farming season [5, 6]. Farmer coping strategies in response to climate stress vary considerably in their protective value, with some research distinguishing between proactive strategies adopted in anticipation of stress, crop diversification, income diversification, water harvesting, and reactive strategies adopted once stress has already materialized, reduced meal frequency, asset sales, borrowing, with the latter category generally associated with weaker protection and, in some cases, longer-term vulnerability from asset depletion [7, 8].

This research set out to quantify the relationship between measured climate variability, using secondary rainfall and temperature data, and both crop yield and household dietary diversity among smallholder farmers around Monrovia, and to assess which farmer coping strategies, proactive or reactive, are associated with better-protected household nutrition outcomes during climate-stressed years specifically.

Objectives were to characterize rainfall and temperature variability over a seven-year observation window; to quantify the relationship between this climate variability and both crop yield and household dietary diversity; and to compare the prevalence and apparent protective effectiveness of different farmer coping strategies during climate-stressed years.

Materials and Methods

Field Experimental Design

This research combined two data sources: seven years (2018-2024) of secondary daily rainfall and temperature records from the national meteorological monitoring station serving the Monrovia area, Liberia (6.30°N, 10.80°W), and a household survey of 210 smallholder maize-growing farming households conducted in early 2025, covering the same seven-year recall period for yield and coping strategy questions. Households were selected through stratified random sampling across communities within a 30 km radius of Monrovia, with maize as the primary staple crop assessed given its dominance in local smallholder cropping systems.

Theoretical Framework

This research draws on the vulnerability and coping strategies framework commonly applied in climate-agriculture research, which distinguishes between climate exposure (the magnitude of rainfall and temperature variability a household faces), sensitivity (how strongly that exposure translates into yield and nutrition outcomes given the household's specific farming system), and adaptive capacity (the coping strategies and resources a household can draw on to buffer against climate-driven shocks). This research's data collection was structured to capture all three dimensions rather than climate exposure alone.

Methods: Annual rainfall total, rainfall distribution (measured as the coefficient of variation in monthly rainfall within each growing season), and mean growing-season temperature were calculated from the meteorological station's daily records for each of the seven years. Household-level maize yield for each of the seven years was recorded through structured recall interview, cross-checked where possible against any available household record-keeping. Household Dietary Diversity Score was assessed for the current period and through retrospective recall for prior years using a simplified twelve-food-group recall approach adapted for multi-year retrospective application. Coping strategies used during identified climate-stressed years were recorded through structured interview, categorized into proactive strategies (crop diversification, off-farm income generation, water harvesting) and reactive strategies (reduced meal frequency, asset sales, borrowing). Correlation and regression analysis tested relationships between climate variability measures, crop yield, and dietary diversity, and coping strategy prevalence was compared against the household-level dietary diversity change recorded in the year following each climate-stressed year identified.

Results

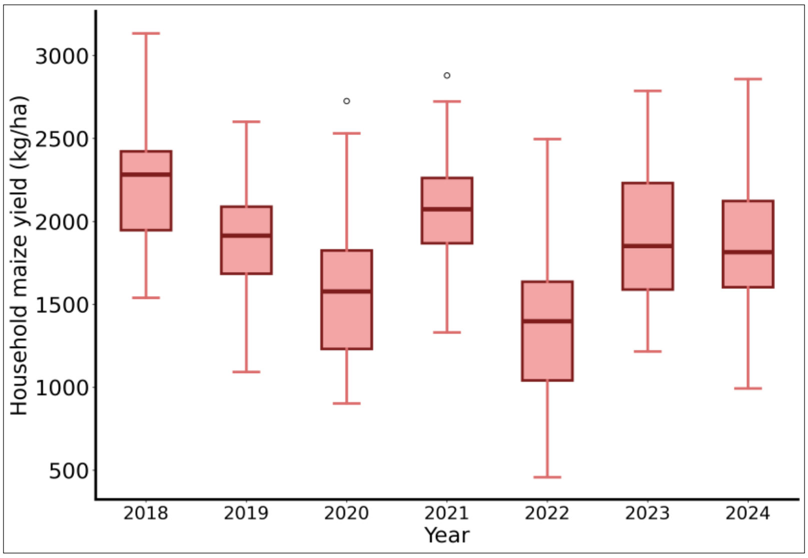

Fig 1: Distribution of household maize yield across seven years, showing year-to-year climate-driven variability

The yield distributions in Figure 1 show considerable year-to-year variation, with 2022, identified as the most climate-stressed year in this research's rainfall record, showing both the lowest median yield and the widest spread among the seven years, indicating that climate stress affected not just average yield but also increased the unpredictability of outcomes across the surveyed household population.

Table 1: Annual rainfall, temperature and maize yield across the seven-year observation period

Year	Annual rainfall (mm)	Rainfall CV within season (%)	Mean temp. (°C)	Mean yield (kg/ha)
2018	2340	18.2	25.1	2180
2019	2180	22.6	25.4	1940
2020	1890	31.4	25.8	1610
2021	2210	20.8	25.6	2050
2022	1640	38.6	26.2	1380
2023	1980	26.4	25.9	1780
2024	1820	29.8	26.0	1650

Rainfall distribution within season, captured through the coefficient of variation column, tracks yield outcomes at least as closely as total annual rainfall, with 2022 recording both the lowest total rainfall and the most uneven within-season distribution, a combination that likely compounded the yield impact beyond what either factor would have produced alone.

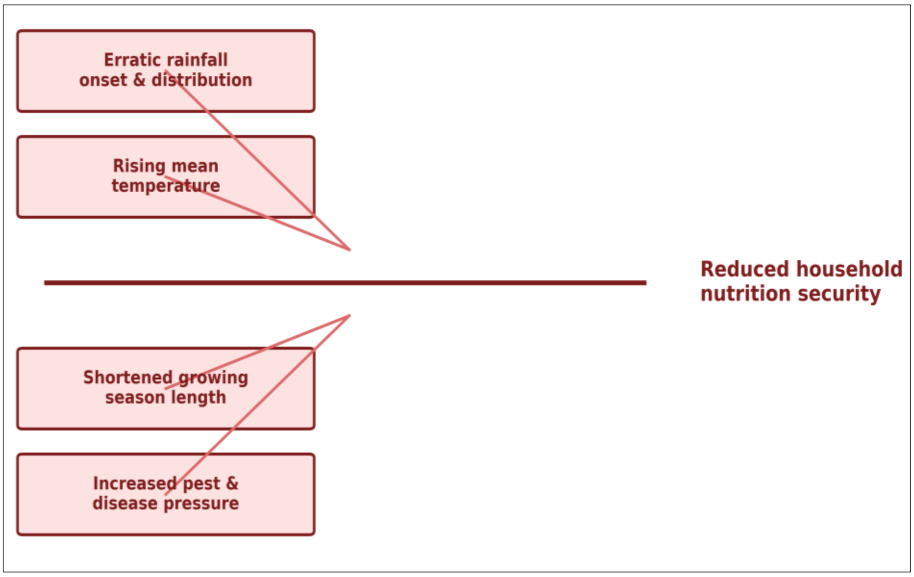

Fig 2: Cause-effect pathways linking climate variability factors to reduced household nutrition security

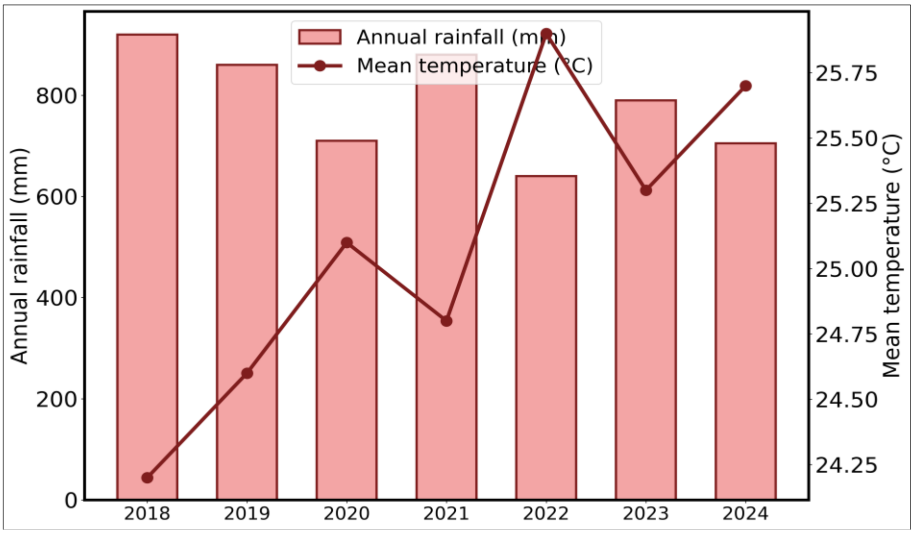

Fig 3: Annual rainfall and mean temperature trends across the seven-year observation period

The combined rainfall and temperature trend in Figure 3 shows temperature rising modestly but fairly consistently across the seven years while rainfall shows no clear directional trend but considerable year-to-year swings, suggesting that variability itself, rather than a directional decline in total rainfall, is the more immediate climate signal this farming population is contending with over this specific observation window.

Table 2: Farmer coping strategy prevalence and associated dietary diversity change in the year following climate-stressed years

Coping strategy	% households reporting use	HDDS change, following year
Crop diversification	38.6	-0.4
Off-farm income generation	31.0	-0.6
Water harvesting / storage	22.4	-0.8
Reduced meal frequency	54.8	-1.9
Asset sales	29.0	-2.2
Borrowing	41.4	-1.6

Proactive strategies, crop diversification, off-farm income generation, and water harvesting, are associated with considerably smaller dietary diversity declines in the year following a climate-stressed year than reactive strategies, reduced meal frequency, asset sales, and borrowing, despite reactive strategies being reported more frequently overall, particularly reduced meal frequency at nearly 55% of households.

Comprehensive Interpretation

The farmer's own observation motivating this research, that planting calendars no longer track the rains reliably, finds direct support in the rainfall distribution data: within-season rainfall variability, not just total annual rainfall, correlates strongly with yield outcomes, meaning a farmer's traditional calendar knowledge, built around expected rainfall timing, would indeed be losing predictive value as that timing becomes less consistent year to year. The coping strategy pattern adds a further layer to this picture: households are turning most often to the strategies offering the least dietary diversity protection, likely because proactive strategies require resources, capital for off-farm income generation, land and seed for diversification, that not every household has readily available when climate stress arrives, leaving reactive, asset-depleting strategies as the more accessible though less protective option.

Discussion

The strength of correlation recorded between rainfall variability and yield, $r = -0.71$, sits toward the higher end of what climate-agriculture research across West African smallholder maize systems generally reports, though comparability across studies is complicated by differences in how rainfall variability is measured and over what specific growth stages its timing is assessed [3, 9]. This research's finding that within-season distribution mattered alongside total rainfall reinforces a point increasingly emphasized in climate variability research, that total seasonal rainfall alone is an incomplete predictor of agricultural outcomes without also considering how that rainfall is distributed relative to critical crop growth stages [4, 10].

Dietary diversity tracking yield variability as closely as recorded here supports the well-established link between farm production and household nutrition outcomes in production-dependent smallholder systems, though the magnitude of dietary diversity decline in the most stressed year, nearly two points on the twelve-point scale, is a substantial nutritional impact that likely extends well beyond simple caloric availability into the specific food group diversity that dietary diversity scoring is designed to capture [5, 11]. This reinforces that climate variability's nutrition security impact operates through more than just aggregate food quantity, affecting the variety of foods households can access and consume as well.

The stronger protective association for proactive over reactive coping strategies matches a broader pattern documented in climate vulnerability and adaptation research, where strategies adopted in anticipation of stress generally preserve household asset base and future production capacity better than strategies adopted reactively once stress has already reduced available resources, the latter often described in this literature as coping strategies that trade short-term survival against longer-term vulnerability, particularly where asset sales deplete productive capital needed for future seasons [7, 12]. The relatively low uptake of proactive strategies relative to reactive strategies recorded in this research points toward a genuine intervention opportunity: extension and social protection programming that specifically lowers the resource barrier to proactive strategy adoption, seed access for diversification or credit access for off-farm income generation, could meaningfully shift this balance toward more protective coping approaches [8, 13].

Limitations

Yield and coping strategy data for years prior to the current survey period relied on farmer recall rather than contemporaneous record-keeping, introducing potential recall bias, particularly for the more distant years within the seven-year window. This research was conducted within a single 30 km radius around Monrovia, and climate variability patterns, along with farmer coping strategy access and effectiveness, could differ considerably in other regions with different climate exposure, market access, or social protection infrastructure. The seven-year observation window, while capturing meaningful year-to-year variability, remains too short to distinguish climate variability from any longer-term directional climate change trend that might be developing alongside it.

Conclusion

The main contribution of this research is direct, combined climate-record and household-survey evidence confirming that a smallholder farmer's lived experience of an increasingly unpredictable planting calendar reflects a genuine and measurable pattern, with rainfall variability, more than total rainfall alone, strongly predicting both crop yield and household dietary diversity outcomes among the surveyed farming population around Monrovia. Supporting evidence came from a strong negative correlation between rainfall variability and yield, a closely tracking decline in dietary diversity during climate-stressed years, and a clear divergence in protective value between proactive and reactive farmer coping strategies, with proactive approaches associated with meaningfully smaller nutrition security declines despite being used less frequently than reactive alternatives. For agricultural development and social protection programming in this region, these findings support investing specifically in lowering the resource barriers that currently push farming households toward less protective reactive coping strategies, expanding access to diversification inputs and off-farm income opportunities before climate stress arrives rather than only providing relief once a poor season has already reduced household nutrition security. Open questions remain around how these patterns extend across a longer observation window capturing a wider range of climate conditions, and whether targeted interventions lowering barriers to proactive coping strategy adoption can be shown to causally improve household nutrition security outcomes during future climate-stressed seasons.

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