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ORIGINAL RESEARCH ARTICLE

Effect of temporal variability of rainfall on sorghum yield in Sakwa, Zaki Local Government Area, Bauchi State

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ABSTRACT

The study investigates effects of rainfall variability on temporal scale and seasonal distribution on yield of sorghum (*Sorghum bicolor L. Moench*) during a four-year period (2022-2025) in Sakwa, Zaki L.G.A. Bauchi State, Nigeria, based on monthly total and sorghum grain yield values. Rainfall pattern was unimodal across all years, very minimal (nil) from December through March, sudden upswing from April through a peak in August, however seasonal variation in annual total rainfall was quite pronounced, ranging between1019 mm in 2022 and a four-year high of 1347 mm in 2023 and down to 788mm in 2024 and 576 mm in 2025.Sorghum yield exhibited reverse relationship to rainfall trend, with no positive relationship detected. The least yield of 0.4 t/ha was realized in the wettest year 2023 with 1347 mm of rain and increased to 1.9 t/ha in the dry moderate rainfall year 2024 (788 mm rainfall) and then decreased to 0.7 t/ha in the driest year 2025 (576mm rainfall). The results confirmed the negative impact of excessively rainy years 2022 - 2023 leading to very low sorghum yields of 0.5 & 0.4 t/ha, potentially owing to waterlogged or leach-out stresses. Moderate rainfall season, 2024 in which the highest yield was recorded, possibly indicated favorable condition close to ideal soil moisture in some critical sorghum growth phase. In essence, neither average yearly total rainfall nor seasonal unimodal rainfall adequately explain variation in sorghum grain yield in the Sudan savanna of Zaki; it appeared seasonal distribution of rainfall and moisture content during the critically important booting stages (July-August) with its related anthesis more strongly influenced yield outcomes under climate induced extreme variability. These results suggest that climate- smart farming practices such as good water drainage facilities; better adapted crop husbandry practices like modified planting dates as well as resilient planting waterlogged and drought stress sorghum varieties might be needed to buffer effects of changing temporal pattern of rainfall.

Keywords: Rainfall variability; Temporal distribution; Sorghum yield; Sakwa; Bauchi State; Nigeria

Introduction

Rain-fed agriculture is entirely reliant upon the amount, time and seasonal distribution of rainfall. This makes them extremely sensitive to the effects of climate change. This results in their great vulnerability to climate change effects. This is amplified even more in sub-Saharan Africa that has farming communities heavily impacted by effects of climate change (Nyoni et

al., 2020). Existing weather conditions, namely extremes of hot and cold, drought, variations (spatial and temporal) of amount and intensity of rain and severe storms hinder food production by limiting availability of soil water, causing delays in germination of crops, inhibiting growth and reducing crop yield and productivity (Habib-ur-Rahman et al., 2022). The IPCC (2022) further corroborates this by acknowledging the fact that climate variations pose dangers to African security in terms of food by worsening already changing climates and extreme events. Northern Nigeria's Sudano-Sahelian zone is an example of this in practice. Rainfall variability is high; not only inter-annually but also intra-seasonal (Njouenwet et al., 2022). The study further reported that total precipitation is rarely a concern, rather distribution over the season and significant temporal variation is. Heavy rain or extended dry periods erase the usefulness of 'high' totals, while moderate, even rain is more beneficial for a good harvest.

Sorghum, an important substitute rain fed cereal is often a water resource-smart crop that rarely needs to be irrigated. But due to its robustness to climate adversities, like some other cereal genotypes, is vulnerable to changes in rainfall. Water needs of the cultivar average of 450 mm to 650 mm is good enough for maximum yields (FAO, 2024); depending on water-use efficiency under changing weather-pattern over the years and the adequate moisture during the stages of anthesis and onset of caryopsis development (Zhang et al., 2023). Rainfall is imperative during the reproductive period for maximizing the potential yield, where availability of water sources at certain sensitive developmental stages is paramount such as antenesis and inception of the grain development stage due to the sensitivity of the plants towards edaphic moisture deficit (Ikpe et al., 2024). Besides, during seed-based propagation, although rainfall is necessary for seed-germination in sorghum, too much of rain during these stages have a negative impact on crop initiation (Zhang et al., 2023). Moreover, if drought situation persists at some specific period during the life span, then it would lead to drought at most important growth phases, impacting sorghum production drastically (Ikpe et al., 2024).

The analysis performed in the following studies suggests significant variability in the correlation between rainfall and yield of various crops across Nigeria. The work of Ikpe et al. (2024) in Bauchi State analyzes 30-year data of rainfall to ascertain its correlation with sorghum. The results suggest a non-significant positive relationship ($r = 0.3035$) between Rainfall and Sorghum yield, revealing that increases in precipitation were not consistently translated to higher sorghum yields. In the Potiskum Local Government Area, Yobe State, research demonstrated inconsistency of watering system and inconsistencies of changes of variation in sorghum yields, thus indicating a correlation between Rainfall and sorghum yields (Ejeh & Ikpe, 2024). Mwamahonje et al. (2024) suggested that this crop is vulnerable to highly intermittent rainfall so sorghum farmers require learning about global warming (also known as climate change) and adjust for it. In general, the abovementioned research would generally argue that this will have both positive and negative impacts on sorghum crop due to the impact of the accumulated annual precipitation on whether the sorghum farmers were able to understand the production effects of the rainfall properties for producing Sorghum. For instance, (Ariko et al., 2024) also mentioned how many variations exists in climate trends including various different spatial patterns of the trends and concluded that this could also either prompt the occurrence of beginning of planting season or cause the season to be

delayed due to various different spatial variations. They further projected that it is important to take planting seasons into account while analyzing rainfall totals in general.

More importantly, overall rainfall variabilities were observed to be of significance contribution toward production of sorghum in Nigeria (Ariko et al., 2024). In spite of these results, major spatial and temporal gaps still exist. The vast majority of the previous research undertaken in the study area in northern Nigeria has relied upon long time-series (over multiple decades) and has, quite regularly, discussed the yearly total amount of rain, or general relationship between rainfall and yield (Ahmad et al., 2025). Whereas, such analysis is necessary for assessing longer- term fluctuations of climate variables, it will likely hide the inter-seasonal fluctuation on the pattern of rainfall, and consequently affect farmers directly within each rainy season. This is likely to occur where rainfall season commences on time, but ends too early. This study suggests analysis using both yearly and monthly rainfall totals and rainfall onset and cessation dates as well as periods of no rainfall during the season might present a better view of what limits the production of sorghum on the ground at local scale.

Rainfall variations have impacted on growth and timely termination of Sakwa agricultural zone. The Sakwa locality, located in Zaki Local Government Area, Bauchi State, is one of the farming communities where planting of sorghum is heavily dependent on the pattern of the rainy season. In this light, the onset of rainy season, number of rainy days and termination of the season can be linked to variations in length of the growing period as well as occurrence of important water at some critical crop growth period. Data from recent growing seasons show strong association between variations in rain pattern and substantial fluctuations in sorghum harvest (Ikpe et al., 2024). Notably, prolonged periods of hydric deficit occurring within the crop's vegetative cycle may exert a more profound impact than the cumulative annual precipitation, primarily because moisture stress during the reproductive phase directly impairs caryopsis development.

Analyzing the influence of the amount and temporal distribution of rainfall on the sorghum performance in Sakwa is of importance. This allows to distinguish between years of surplus, optimum and deficit/pre-mature rainfall. In addition to knowing whether the lower yield than in other years is related to flooding, deficit or asynchronism of rainfall. Thus, enabling farmers to change the methods of planting, selecting varieties, water utilization and forecast usage. Our study will examine how varied rainfall patterns and distribution affect sorghum output in Sakwa, Zaki local government area, Bauchi. We would concentrate on yearly rain shifts during the growing season (2022-2025). The aim is to relate rainfall characteristics to sorghum yield and to identify the rainfall conditions associated with higher or lower yields. Ultimately, our findings will provide practical guidance for managing weather risks and strengthening sorghum cultivation against uncertain precipitation.

Materials and methods

Study area

The present study was conducted in Sakwa, which is an area within the Zaki Local Government Area of Bauchi State in the Northeast geo-political zone of Nigeria, it is bounded by geographical coordination between circa 12° 07' 13.411" N, 100° 17' 13.011" E (Figure 1).

within such susceptible geographical context. Environmental issues have made the landscape exposed to effects of arid periods (drought), aeolian and fluvial erosion, therefore the levels of the geological and geo-environmental degradations are greatly elevated. Geologically, this region is a product of Chad Formation under a Sahelian savanna. As the region is predominately under agricultural practice the level of agricultural yield often faces critical failure caused by severe moisture deficit as a result of frequent prolonged period of drought which affects the practice of agriculture. Low stouter trees and shrubs describe the vegetation in the study area.

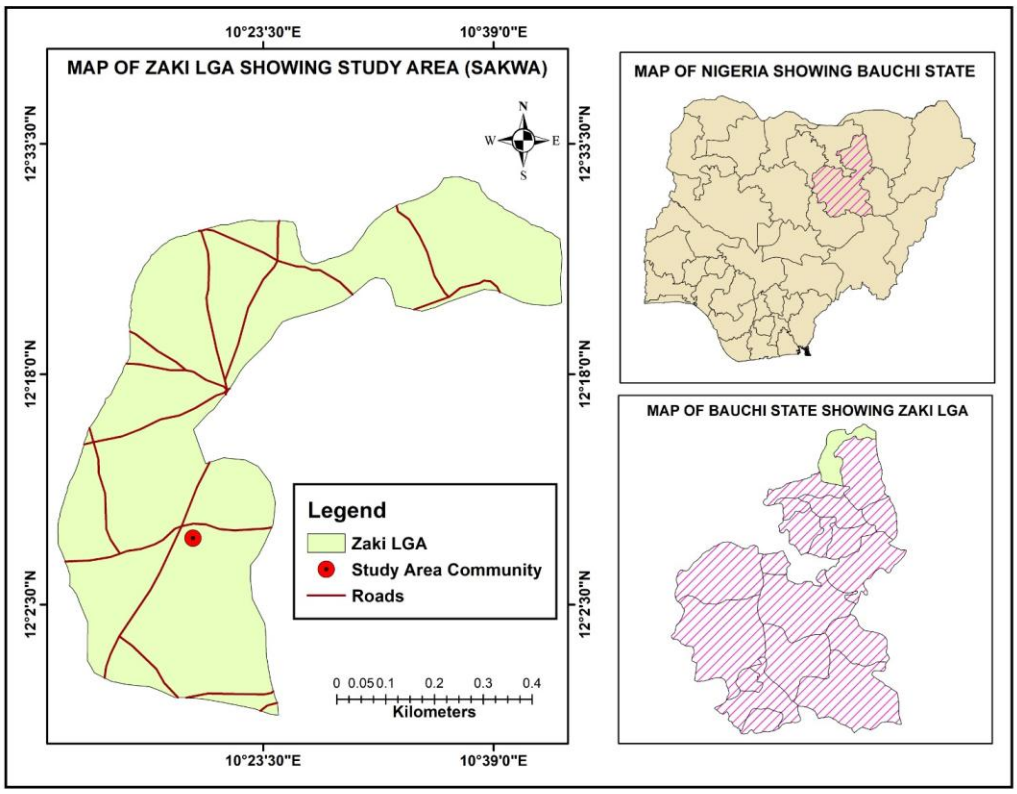


Figure 1: Zaki map showing study area (Sakwa)

Data sampling

The research involves four-year data (2022-2025) for Sakwa, obtained from the Bauchi Meteorological (NiMET) station, which records rainfall for villages, cities and local government areas across Bauchi State. The annual average sorghum yield per hectare data for Sakwa were sourced from the office of Bauchi State Agricultural Development Project (BASADP), Azare branch, which records the yield per hectare of all crops in Sakwa each year. Monthly rainfall totals (mm) were summed to obtain the annual rainfall total for each year, and the monthly distribution of rainfall (onset, peak months, cessation and months with no rainfall) was compared across the four years. Year-to-year changes in annual rainfall and in sorghum yield (t/ha) were expressed as percentage changes relative to the preceding year. Annual sorghum yield was then compared with the annual rainfall total and with the monthly rainfall distribution of the same year to assess the relationship between rainfall and yield. Because the data set covers only four years, the analysis was descriptive and no inferential statistics were applied. The data were organized and plotted using the Multi Panel/2D facility of OriginPro (OriginLab, 2024).

Results and discussions

Data presented in Tables 1 and 2, along with Figure 2, consistently illustrate a uniform seasonal precipitation pattern across the four-year period within the Sakwa district of Zaki Local Government. Annually, an identical meteorological pattern was observed, characterized by negligible or absent precipitation from November to March, followed by a distinct escalation commencing in April. Similar results were noted by others (Ariko et al., 2024). The primary period of elevated precipitation occurred between June and September, succeeded by a precipitous decline by October (Abubakar et al., 2024). This substantiates a stable, unimodal precipitation regime, rather than indicative of a shifting climatic pattern. Similarly Figure 2 and Table 2 also show relatively same unimodal seasonal rainfall during the entire study period 2022 - 2025 and peak months for precipitation occurs around July - August, annually. However, total amount for yearly precipitation did not remain constant rather it increased from 2022 to reach high of 1347 mm in 2023 and gradually decreases to 576 mm in 2025. This is attributable to less rainfall amounts within the months of July - September which are peak monsoonal months. Our current findings are in line with what has been found by Ikpe et al. (2024) in the same state.

Table 1: Monthly rainfall trend in Sakwa (2022-2025)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	A.total
2022	0	0	4	18	72	164	285	320	191	53	2	0	**1,109**
2023	0	0	3	36	96	205	295	355	275	81	1	0	**1,347**
2024	0	0	3	20	105	178	115	152	96	28	1	0	**788**
2025	0	0	2	12	86	127	94	141	88	25	1	0	**576**

A = Annual

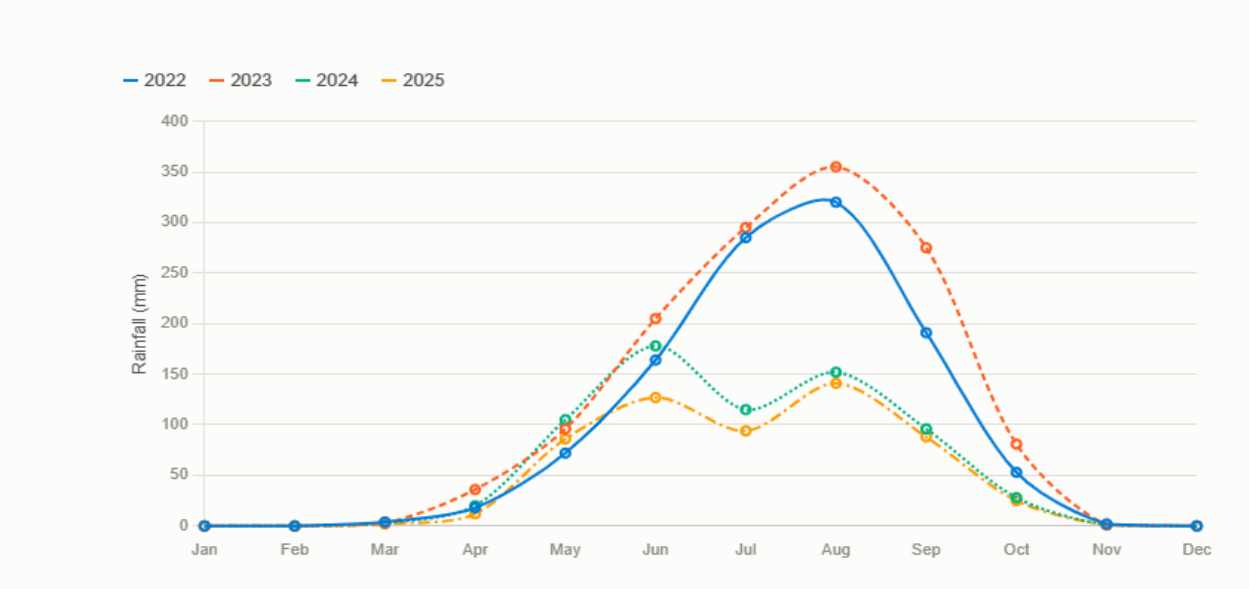


Figure 2: Monthly rainfall pattern (2022-2025) in Sakwa

Table 2: Year-on-year monthly rainfall comparison for Sakwa

Month	2022	2023	2024	2025	Trend
Apr	18	36	20	12	Volatile, no clear direction
May	72	96	105	86	Peaked in 2024, slight pullback in 2025
Jun	164	205	178	127	2023 highest, declining since
Jul	285	295	115	94	Sharp drop from 2023 to 2024 (–61%), continuing to fall
Aug	320	355	152	141	Peak month every year, but magnitude roughly halved after 2023
Sep	191	275	96	88	Same pattern — steep decline post-2023
Oct	53	81	28	25	Tapering in step with the wider decline

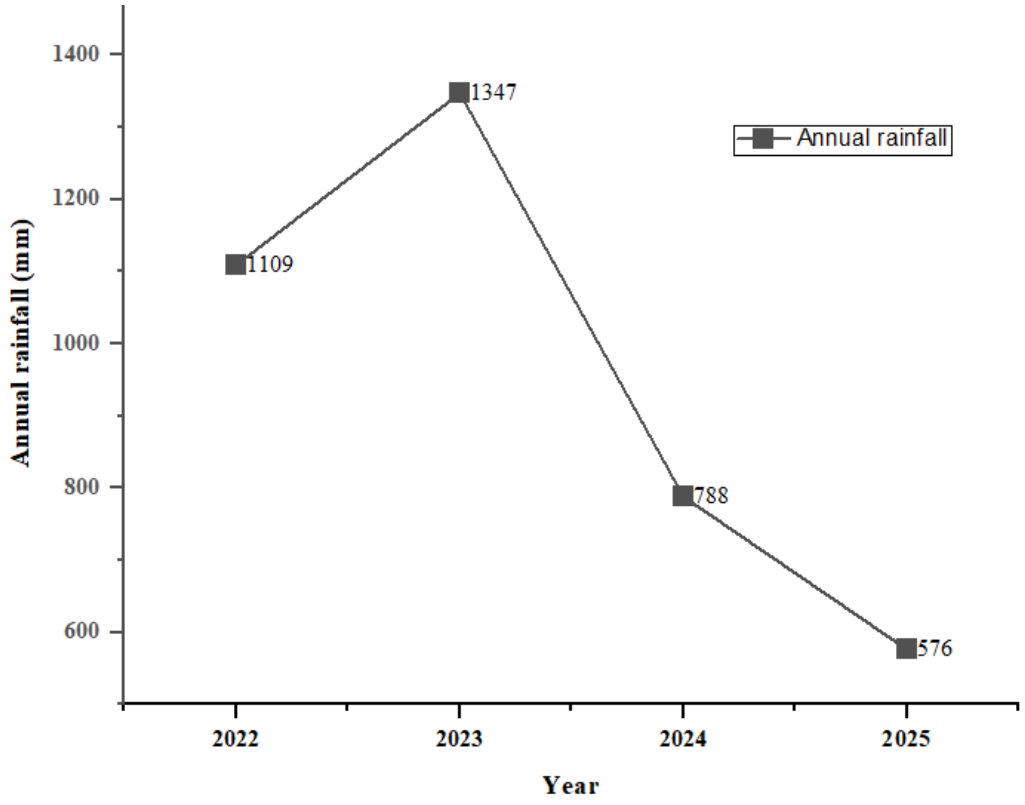


Figure 3: Annual rain trend in Sakwa town

Figure 4 and 5 illustrate the trajectory of sorghum yield per hectare across the 2022–2025 cropping seasons in Sakwa, Zaki Local Government Area, Bauchi State. Sorghum yields exhibited significant year-on-year variability over the duration of the study, spanning from a minimum of 0.4 t/ha in 2023 to an apex of 1.9 t/ha in 2024 — representing nearly a five-fold disparity within this four-year observation period. A modest reduction occurred from 0.5 t/ha in 2022 to 0.4 t/ha in 2023, followed by a dramatic escalation to 1.9 t/ha in 2024—an approximately 375% increase from the preceding year. Subsequently, a significant downturn led to 0.7 t/ha in 2025, a decrease of roughly 63% from the 2024 peak, yet still marginally surpassing the 2022 and 2023 figures.

The overall pattern is characterized by its non-linear and highly volatile nature. Similar with results reported by Agele et al. (2025). The year 2024 stands out as a distinct outlier of exceptional productivity, flanked by relatively lower and more closely clustered yields in the other periods (0.4–0.5 t/ha in 2022–2023; 0.7 t/ha in 2025). This observed pattern indicates that local agricultural productivity is not governed by a consistent monotonic trend but is profoundly influenced by annually specific environmental and management factors. Such factors most plausibly include the temporal distribution and intensity of precipitation (Figure 3) alongside other dynamic agronomic inputs like nutrient application, incidence of pests and diseases, and specific cultivation practices. The explanation agrees with findings of others (Asfaw et al., 2018; Agele et al., 2025).

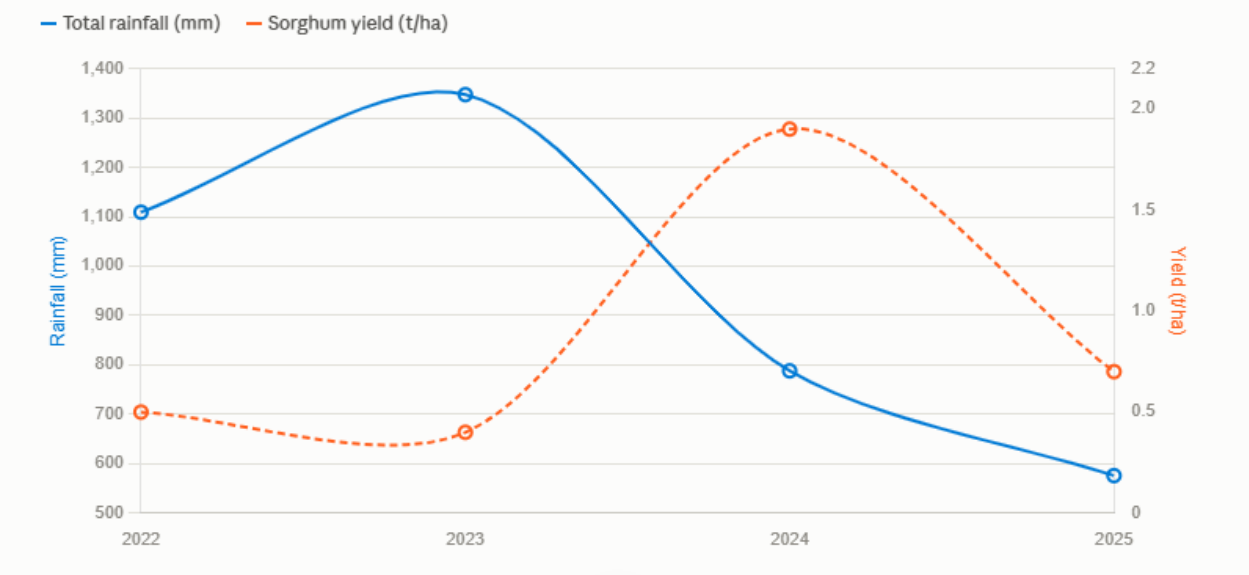


Figure 4: Rainfall trend Vs Sorghum yield /ha

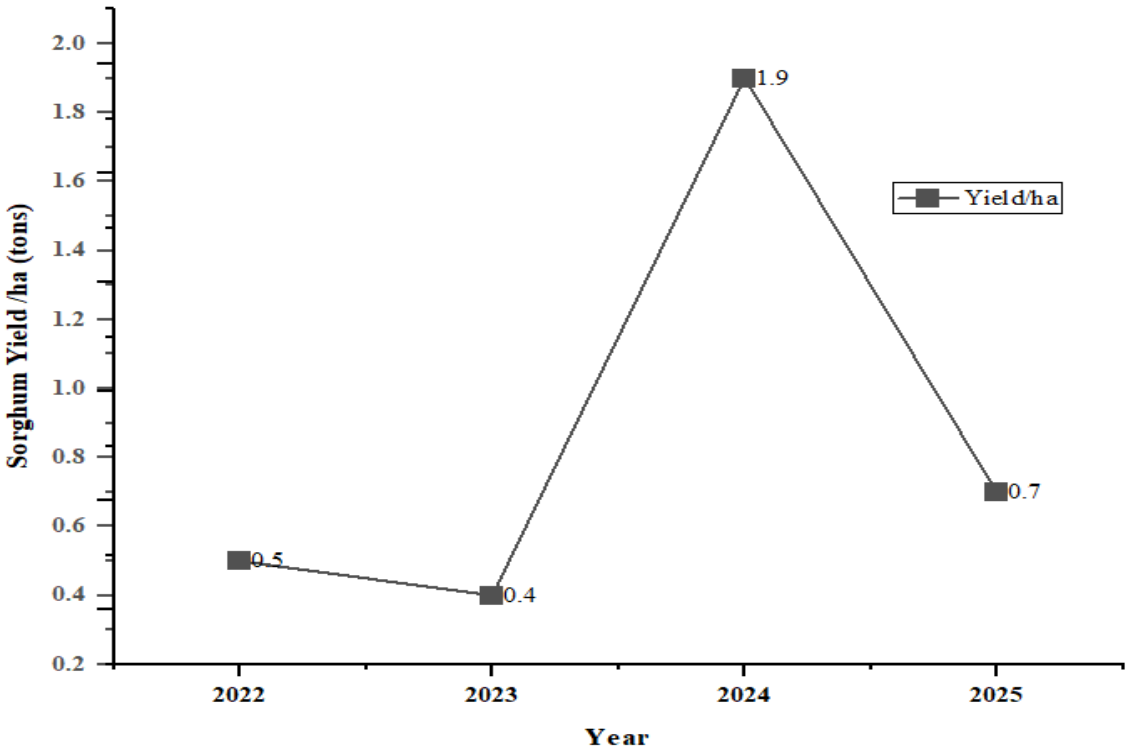


Figure 5: Sorghum yield/ha between 2022-2025 in Sakwa town

Conclusion

The monthly rainfall data show a broadly unimodal seasonal pattern in Sakwa during 2022–2025, but annual rainfall totals varied markedly, rising from 1019 mm in 2022 to a peak of 1347 mm in 2023 and then falling to 788 mm in 2024 and 576 mm in 2025. A reverse relationship existed for sorghum production, being greatest during a year with only 788mm (2024, yielding 1.9t/ha), and smallest during the wettest year, which received 1347mm and only yields 0.4 t/ha sorghum production (2023). This implies over-watering hinders sorghum yields likely by leading to water logging, a flushing out of nutrients, and the development of diseases. Despite there being very limited information, we can infer that in Sakwa the yield of sorghum appears more affected by the timing and amount of rain per occurrence (the actual number of wet days) compared to total rainfall. Therefore, rather than increasing overall water supply we need to consider ways to manage the amount and timing of watering, for example using improved drainage or adopting new crop species, for stable crop yields. Future studies will explore the impacts of daily rainfall data, and include an assessment of non-climatic factors such as soil health, diseases, and the particular crop varieties grown on sorghum yields and this topic can and should be expanded.

Declarations

Author contributions (CRediT): *Not applicable*

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Conflict of interest: *Not applicable*

Ethics approval and consent (where applicable): *Not applicable*

Data availability: *Not applicable*

Use of AI tools (where applicable): *Not applicable*

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