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IMPACTS OF CLIMATE VARIABILITY ON SUSTAINABLE AGRICULTURAL WATER MANAGEMENT IN YAURI, NORTHWESTERN, NIGERIA

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ABSTRACT

Climate variability is greatly affecting water management and agricultural productivity particularly in semi-arid region like Yauri which experiences both flood and drought. This study examines the impacts of climate variability on sustainable agricultural water management in Yauri, Northwestern, Nigeria, using 30 years of meteorological data integrated with field surveys of agricultural water management practices. Descriptive statistics, including the Precipitation Concentration Index (PCI), Temperature Anomaly Index (TAI), Mann-Kendal trend test, and Sen's Slope Estimator were applied to assess rainfall and temperature variability, trends, and anomalies. Total seasonal rainfall, onset, cessation, and length of growing season were also analyzed to determine implications for agricultural water use. Results show an average annual rainfall of 110.3 mm with 20.49 % coefficient of variation, indicating moderate variability. The rainy season lasted 135-178 days (average 164 days). PCI values (16.30-23.81) indicated moderate to irregular rainfall distribution, while trend analysis revealed a slight but statistically insignificant rise in seasonal rainfall ($+4.52\ mm\ year^{-1},$). Temperature trends show a significant increase in minimum temperature (+0.074 ℃ $year^{-1}$, p<0.001), and a modest rise in maximum temperature (+0.0346 ℃ $year^{1}, p = 0.07$), signifying a warming trend. The TAI indicated pronounced dry-season warming and wet-season cooling anomalies Field Surveys revealed 84.66 % of farmers depend on groundwater, 91.35 % use traditional surface irrigation, and over 80 % lack water storage facilities. Key challenges include poor policy awareness, inadequate infrastructure, and inefficient water use. The study demonstrates that rising temperatures and erratic rainfall are affecting water availability and agriculture in Yauri, and recommends the implementation of smart-climate technologies, improved irrigation and storage infrastructures, and farmers training to ensure sustainable agricultural production under changing climatic condition.

Keywords: Climate Change, Sustainable Agriculture, Water Management, Yauri, Nigeria

INTRODUCTION

The global climate is changing at alarming pace, with increasing surface temperatures and irregular patterns of rains. Human activities that produce greenhouse gases, as well as natural climate cycles, are responsible for bringing about the changes. The National Centre for Environmental Information (NCEI, 2023) reports that global temperatures have increased at faster rate over the past century. In fact, 2023 was the warmest year ever recorded since the measurement began in 1850 with a temperature of 1.18 ℃ higher than the 20th-Century average, which beat the previous records in 2016 by 0.15 ℃. The years from 2014 to 2023 have the ten hottest years ever recorded, which shows ongoing global warming, that was further supported by the EI Niṅo event in 2023 (NCEI, 2023; Raghuraman et al., 2024).

In addition to the rise in global temperature, precipitation regimes have also been more unpredictable due to intensification of hydrological cycles by anthropogenic greenhouse gas emission and atmospheric warming. Zhang et al. (2024) reported that anthropogenic warming has amplified rainfall variability across more than 75 % of the earth's land surface, most significantly in Australia, Europe, and Eastern North America. This pattern is marked by more frequent heavy precipitation interspersed with longer dry spell which, raise the risk of both flood and drought. Westra et al. (2013) and Zhang et al. (2024) also noted that the global daily rainfall variability has increased by approximately 1.2 % by decade since 1900s, with noteworthy acceleration after 1950s. consequently, rainfall is becoming more focused on fewer days, which is increasing the occurrence of more extreme events complicating water management and agricultural planning. These changes largely brought about by greenhouse gas accumulation, have warned the atmosphere, raised it water-holding capacity, and energized the global hydrological cycle.

Higher climate variability has increased the frequency and severity of extremes of events such as irregular rainfall, drought, heatwaves, and flood that disrupt crop growth, reduce yields, and raise global crop loss risks by altering soil water and moisture (FAO, 2023). Heatwaves accelerate evapotranspiration, degrade grain development, and affect heat-sensitive crops such as maize and soya beans significantly (Qu et al., 2023). Rising temperatures and changing rainfall decrease growth periods, and reduce yield potentials for crops, particularly in tropic and subtropics where small warming can exceed the threshold of tolerance crops. The FAO (2023) documented yield loss averaging up to 5% annually in wheat in Morocco, and maize in South Africa between 2000 and 2019, mainly caused by temperature, drought, and excess rainfall. Globally, maize productivity is likely to decline by as much as 24% at the turn of the century on current trajectories, while wheat productivity may initially increase in some temperate regions before plateauing sometime in the mid-century (Jägermeyr et al, 2021). These impacts undermine economic resilience and food security, particularly among the small-scale farmers with weak adaptive capacity.

Water timing and availability for agriculture have been disrupted by elevated temperatures and altered precipitation regimes that augment evapotranspiration and crop water demand, while recurrent heatwaves and droughts intensify water stress and lower water-use efficiency. The limitation is particularly acute in arid and semi-arid regions, where water constrains already limit crop production. Hamed et al. (2021)

further found that droughts and extreme in combination can reduce the yield of maize and soybeans by another 5-9 %, emphasizing the interactive impact of temperature-moisture crop yields. While there can be small increase in yield in temperate regions, tropical, and subtropical regions face heightened risks of productivity loss. Increasing climatic unpredictability makes water allocation and irrigation planning more challenging, typically resulting inefficient use of water and greater vulnerability to floods and droughts. Climate change intensifies stress on agricultural water resources through disruption of hydrological cycles and exacerbation of water shortages in prominent food producing-regions (Cotera et al., 2024; OECD, 2014). These developments call for revolutionary water management strategy to attain food security and sustainable agriculture. Optimal agricultural water management enhances efficient use of limited water resources, meeting up crop water demand with a minimal waste. Jägermeyr et al. (2017) demonstrated that the integration of an improved irrigation with climate-resilient crop varieties have the potential to reduce water demands by up to 40%, along with a less energy use and greenhouse gas emission, highlighting its dual roles in adaptation and mitigation. Water-smart agronomics techniques, including rain water harvesting, drought-tolerant crop varieties and soil moisture conservations can enhance water productivity and develop resilient to climate-induced water stress.

Yauri, which is located in the eastern bank of River Niger in the semi-arid region of Kebbi state, Northwestern, Nigerian experiences both flood and drought. Northern Nigeria is characterized by drought and erratic rainfall which occasionally resulted crop failure and yield loss. The reduction of Lake Chad from 40,000 km² to approximately 1,300 km² resulted from prolong drought as reported by Olaniyi, et al. (2019) that caused severe food security and destroyed livelihood of many people in the area. In, 2024, the United Nation Office for the Coordination of Humanitarian Affairs (OCHA) reported that flooding affected 31 states and 180 local government councils in Nigeria, affecting 641,000 individuals and destroying around 750 hectares of farm land (OCHA, 2024). The vulnerability of Kebbi to both flood and drought hazards threats, more so with climate change, will have devastating effects on agriculture and food security (Ayodele et al., 2025). 37,610 hectares of farmlands were destroyed by floods in 2015, and estimated of 26,000 inhabitants were displaced from their households in 21 local government councils of the state (NEMA, 2015). Farms and infrastructures were damaged by intense floods in 2020, with estimated of one million ton of rice destroyed, which accounts for 25% of total rice output in Nigeria (Salisu et al., 2024; Copernicus, 2020). By 2024, a total of 16 out of 21 local government councils in Kebbi state were affected, with principal crops such as rice, millet and sorghum, and beans were destroyed, worsening food security in the region. Alternatively, series of droughts in 2015, 2019, and 2021 led to the huge loss of crops, over 40% of rice paddies destroyed in 2015 alone due to the insufficient rainfall (Buhari et al, 2024).

Effective water resources management under changing climatic conditions is essential for agricultural sustainability in Yauri. However, the limited availability of localized data and uncertainty in climate projection constraint the development of targeted adaptation strategy. While previous studies, such as Salisu et al. (2024) have examined the rainfall and temperatures trends across Kebbi state, comprehensive, localized analyses focused specifically Yauri's agricultural water management remain scarce. Salisu et al., (2024) provide a regional-scale climate trends data, but this study directly fills this gap by using an integration of intensive analysis of climate data with farm survey data regarding agricultural water management practices in Yauri. This allows for proper determination of water-use efficiency, irrigation requirements, and viability of climate-resilient agriculture measures tailored towards the study area. Historical rainfall and temperature records were utilized in determining variability and long-term trends, while crop water requirements were approximated to field-level water use. The study, thus provide site-specific data on the connection on climate variability and agricultural water management in Yauri, and other comparable semi-arid ecosystem. The research will evaluate the impacts of climate variability on sustainable agricultural water management in Yauri; identify the efficiency of water utilization and irrigation demand from climatic and agricultural condition; and identify climate-resilient farming alternatives that enhance food security and resilience of livelihood. The study will guide the formulation of policies, which are based on evidence to guarantee sustainable water management in agriculture in Yauri, Northwestern, Nigeria.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in Yauri, Kebbi state, Northwestern, Nigeria which approximately lies at latitude 10°44'34" N and longitude 4°46'24" with an average elevation of 182 m above the sea level. it is characterized by tropical savanna climate with wet (May-October) and dry (November-April) seasons, the latter being under the influence of Harmattan winds (Olaniyi, et al., 2019). Yauri gets an average yearly rainfall of 1103 mm which is extremely variable form one year to another and has been increasingly more unpredictable with a climatic change. Its average daily temperature fluctuates from 21℃ to 40℃, with a maximum values being experience from March to May. These climatic factors make the region susceptible to frequent, drought, and flood whose effects play significant role in availability of agricultural water availability.

The physical geography of Yauri is undulating to flat topography, with the characteristic of water retention in the surface and induction of agricultural water management. Dominant soil range from clay loam to sandy loam, with moderate fertility but proneness to soil erosion and moisture stress, particularly under poor irregularity of rainfall. Agriculture is the principal source of income in Yauri since over 80% of the population is engage in agriculture and animal rearing (NBS, 2020). There is a combination of rainfed and irrigated farming, and the dominant crops include rice, millet, sorghum, cowpea, and groundnut. In spite of the reality, that River Niger provide excellent prospects for irrigated lowland rice production, irrigation facilities are few and poorly utilized. Consequently, agricultural productivity depends largely rainfed, thus rendering agricultural productivity sensitive to climatic variation.

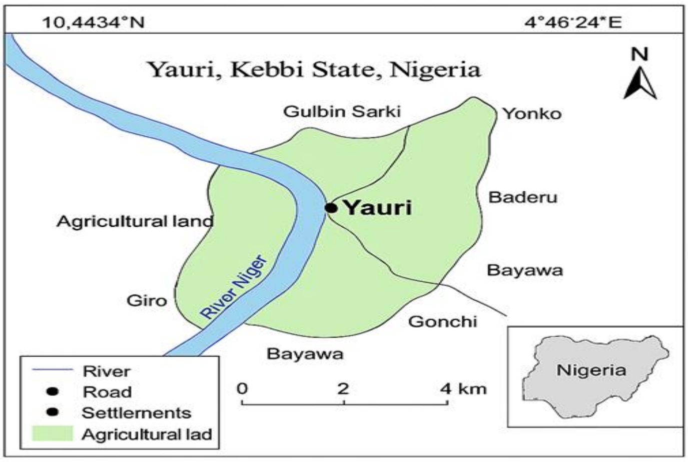

Figure 1: Map of the Study Area-Yauri, Kebbi state, Nigeria

Source of Data

Meteorological factors including daily rainfall, maximum and minimum temperature, wind speed, and relative humidity were obtained from the Nigerian Meteorological Agency (NIMET) station, Yauri covering a period of 30 years (1995-2024). They were properly validated and cleaned to ensure to ensure completeness and accuracy. Missing values were dealt by imputation techniques based on time correlation in the station time series. And inconsistencies and outlier were identified using a range of statistical tests and temporal consistency analysis. Due to the absent of nearby weather station, satellite based meteorological data were employed for cross-validation of the station measurement.

Data on farm water management activities, including irrigation methods, and practices, water sources, irrigation water needs, coping strategies, and climate and environmental data were obtained from the farmers in the study area by field surveys conducted between April, and August, 2025 using 200 structured questionnaires that have response options. The sampling approach employed was a stratified two-stage sampling procedure that gave representative coverage of different categories of farmers in Yauri.

Climate Variability

Onset, cessation, length of the growing seasons, total seasonal rainfall, rainfall frequency, rainfall distribution characteristics, and temperature anomaly were computed using Coefficient of variation (CV), Anomalous Accumulation Method (AAM), Precipitation Concentration Index (PCI), and Temperature Anomaly Index (TAI) which are common in agricultural and climatological characteristics (Asfaw et al., 2018). The analysis was conducted using Python version 3.11

Coefficient of Variation

For the determining the variability of rainfall and temperature in the study area, the coefficient of variation (CV) was employed. CV is a measured described as a percentage of the ration of the standard deviation to the mean which is a scale-free measure of spread. The CV was used as it is good indicator of relative variability, and it is good in comparison across time. Sidi, (2022) described CV values (<20) as low, values (20-30%) as moderate, and values (>30%) as high. The high values signify greater instability and uncertainty in rainfall and temperature pattern which are crucial for drought hazard analysis and adaptive climate planning. Traore, (2023) showed applicability of CV in the assessment of seasonal and annual temperature change, which enhances the understanding of the climate dynamics and their environmental impacts. The CV was computed using equation (1) to assess the degree of variability in the data.

$$CV = \frac{\sigma}{\mu} \times 100 \qquad (1)$$

Where:

σ: Standard deviation

μ: Mean of the dataset.

Anomalous Accumulation Method

The onset and cessation of rainfall during the period (1995-2024) were determined using the Anomalous Accumulation Method (AAM). The method identifies the minimum and maximum of the cumulative anomalies of the rainfall from the long-term mean. The onset is defined as the minimum before the consistent positive departures and the cessation as the maximum before decline. Dunning et al., (2016) demonstrated that AAM is applicable to different regimes of rainfall since it acclimatizes to local climatology, filter out spurious onsets from single rain events, and produce identical results regardless of data source and station density. The flexibility of the method to account for the range of annual rainfall, irrespective of subjective threshold levels, qualifies it for use in a complex climatic region. The AAM also enhances climate prediction by relating onset and demise to moisture dynamics and aids in resources planning by enabling improved seasonality of rainfall regimes. The AAM was derived from equation (2).

$$A_t = \sum_{n=0}^{t} (R_n - \bar{R}) \qquad (2)$$

Where R_n is the measured rainfall at time tn and $\bar{R}$ is the mean rainfall over a specified period.

Precipitation Concentration Index

Precipitation concentration index has been employed to quantify the temporal concentration and distribution pf rainfall. PCI quantifies the degree to which rain is evenly spread out or concentrated over time, typically, month by month or year by year. PCI values (≤ 10) is classified as even distribution, values (10-15) as moderate concentration, values (16-20) as irregular distribution, and values (>20) highly irregular or high concentration of the rain. This classification is dense with information regarding temporal and seasonal rainfall distribution, enabling variability, intensity, and trend analysis in long-term scale (Luis et al., 2011). PCI has been used extensively to study rainfall dynamics at large time scales, yielding valuable information for flood risk analysis, water resources planning, estimation of ground water recharge, and soil conservation planning (Labade et al., 2024;

Luis et al., 2011; Sahu et al., 2024). PCI values were obtained by using equation (3).

$$PCI = \frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2} \quad (3)$$

Where:
P_i: Rainfall in the i-th month (monthly precipitation).
$\sum_{i=1}^{12} P_i$: Total annual rainfall.

Length of the Growing Season
The length of the growing season (LGS) was utilized in assessing the climatic suitability for vegetation growth. LGS is the duration which climatic conditions, primarily rain and temperature, are conducive for plant growth. It was determined by comparing the onset and cessation of the rainfall on a yearly basis during the period of the study to assess temporal trend and variability. This method assesses changes in precipitation patterns and their impacts on crop production with important implications for crop management and climatic adaptation. LGS was calculated using the relation expressed in equation (4).

$$LGS = Date\ of\ Rainfall\ Cessation - Date\ of\ Rainfall\ Onset \quad (4)$$

Total Seasonal Rainfall
The total seasonal rainfall (TSR) was analyzed to assess rainfall variability during the most significant crop production period. TSR is the total precipitation accumulated over a stated season and is derived by summing daily or monthly amounts of rainfall over the growing or wet season of a given year using long-term climatic data. It is important measure in evaluating water availability in hydrology, and climatic studies as it's into consideration the effective rainfall input during the critical period of crop growths. According (Husak et al., 2013), the knowledge TRS is essential in water resources planning and management, particularly in rainfed agriculture. TSR was calculated using relation provided in the equation (5).

$$TSR = \sum_{i=1}^{n} P_i \quad (5)$$

Where:
P_i= precipitation amount in the ith time unit (e.g., day or month) within the season
n = total number of time units in the defined season.

Rainfall Frequency
The rainfall distribution occurrence was investigated using rainfall frequency (RF). RF is one of the important measure of rainfall variability which is expressed as the total number of rainy days over a given period as presented in equation (6). Shift in RF under constant total rainfall can reflect profound climatic change which can provide more information of climate change impacts than cumulative rainfall. A reduction in rainfall frequency linked to more frequent and more intense rainfall increases surface runoff, reduces infiltration,, restrict groundwater recharge, and enhances soil erosion, thus elevating floods and drought risks (Gandhi et al., 2025; Simelane et al., 2024).

$$\text{Rainfall Frequency (\%)} = \frac{\text{Number of Rainy Days}}{\text{Total Days in Period}} \times 100 \quad (6)$$

Temperature Anomaly Index
Temperature Anomaly Index (TAI) was applied to quantify temperature variation and its influence on agro-hydrological processes. TAI quantifies deviations of observed temperature from long-term average, typically from the 30-year climatological reference period for the location. It is a good measure of temperature variations that force evapotranspiration, soil moisture budget, and cross stress factors relevant to agricultural output and water management. Through anomaly capture, TAI enables temperature extreme analysis, drought risks, and shift in agricultural water requirements which facilitates adaptive planning of irrigation against increasing of climate variability (Koudahe et al., 2017). Bogale, (2023) also emphasized the use TAI to identify the impact of climate in agriculture, linking temperature anomaly to yield reduction and water stress. TAI was computed from the formula expressed in equation (7).

$$TAI = \frac{(T_i - \bar{T})}{\sigma} \quad (7)$$

TAI = Temperature Anomaly Index (dimensionless standardized value)
T_i= Observed temperature value at time i (°C)
$\bar{T}$ = Long-term mean temperature over a reference baseline period (°C)
σ = Standard deviation of temperature over the reference baseline period (°C)

Trends and Magnitude of the Data
Mann-Kendall (MK) Test
The Mann-Kendall test was employed to determine the temporal trends of climatic variables. The MK test is non-parametric test for detecting monatomic (trended and non-trended) rising and falling in time series without assuming linearity or normality. It is widely applied in agricultural water management to analyze rainfall and temperature trends that are critical in estimating climate variability and crop water requirements. The test determines if the observations indicate a trend of or increase or decrease over a time by a means of positive and negative S statistics, respectively. The trend significant is tested against standardized Z-score under the null hypothesis of no trend (Hu et al., 2020). MK Statistic was calculated using the formula given in equation (8).

$$S = \sum_{J=1}^{n-1} \sum_{k=j+1}^{n} sgn(x_k - x_j) \quad (8)$$

Where
n is the number of data points
$x_k and\ x_j$ are the data value in time series $k\ and\ j\ (k > j)$ respectively
$sgn(x_k - x_j)$ is the sign function calculated as:

$$sgn\,(x_k - x_j) = \begin{cases} 1\ if\ x_k - x_j > 0 \\ 0\ if\ x_k - x_j = 0 \\ -1\ if\ x_k - x_j < 0 \end{cases}$$

The variance S was computed using equation (9).

$$V(s) = \frac{n(n-1)(2n+5)}{18} - \sum_{t=1}^{q} \frac{f_t(f_t-1)(2f_t+5)}{18} \quad (9)$$

Where
n is the number of data points
q is the number of tied groups
f_t is the number of data value in t^{th} tied group
Z-Statistic was determined using the relation provided in equation (10) to assess the significant of the trend

$$Z = \frac{S}{\sqrt{V}} \quad (10)$$

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{V(S)}}\ if\ S > 0 \\ 0\ if\ S = 0 \\ \frac{S+1}{\sqrt{V(S)}} 1\ if\ S < 0 \end{cases}$$

Under the null hypothesis of no trend, Z follows a standard normal distribution, and significant tests are done at a level α chosen (commonly 0.05). large positive Z values indicate there is an upward, trend, large negative Z values trend indicate that there is negative downward trend and values near zero show no trend (Júnior et al., 2020; Wang et al., 2021).

Sen's Slope Estimator
Sen's slope Estimator was employed to determine the magnitude of rainfall and temperature trends over the study period. The non-parametric method computed the median of all accessible pairwise slopes in a time series and provided an appropriates estimate of rate of change even if there are outliers or non-normal data. Sen's slope is utilized widely in agricultural water management to compute the precipitation and temperature average rate of change, which helps to appraise water availability, crop water demand, and irrigation planning under new climatic condition (Oluwadare & Oluwadare, 2023). The estimator gives the magnitude of a trend usually expressed in unit per year (eg. $mm\ year^{1}$ for rainfall or ℃ $year^{-1}$ for temperature) where positive slopes indicate rising trend, and negative slopes indicate falling trend. The estimates are important for temporal trend evaluation and forecasting to aid data-driven water resources and agricultural planning (Gharsiram et al., 2023). Sen's slope estimator was calculated according to the formula expressed in equation (11).

$$Q = \frac{1}{N}\sum_{j=1}^{n-1}\sum_{k=j+1}^{n}\frac{Y_k - Y_j}{k-j} \quad (11)$$

Where
N is the number of pair (j, k) such that $j < k$
$K_k and\ Y_j$ are the data value in time series $k\ and\ j$ respectively

Crop Water Requirement
The water requirements for millet, sorghum, and rice which are commonly grown in the study area were estimated using decision support system Cropwat 8.0 of Food and Agricultural Organization (FAO). Cropwat determines crop water requirement (CWR) and prepare irrigation schedules based on climatic, crop, and soil information. The Cropwat computes reference evapotranspiration (ETo) from Penman-Montheith equation and calculate the actual crop evapotranspiration (ETc) using crop coefficient (Kc) from equation (12).

$$ETc = ETo \times Kc \quad (12)$$

Where ETc is the crop water requirement. This procedure allows precise estimation of the water requirement at different stages of crop growth. Thus improving irrigation efficiency and minimizing the danger of over or under-watering (Gharsiram et al., 2023). Studies have shown that Cropwat estimate approximately equivalent to field-measured water use. Optimizing water-use efficiency and crop yield. for example, Roushdi (2024) documented improve irrigation scheduling efficiency and water saving of 35-60% compare to conventional method.

RESULTS AND DISCUSSION

Temporal Variability of Rainfall and Temperature
Figure 2 displays the monthly and annual rainfall data for the period 1995-2024 for thirty years. Data analysis revealed the mean annual rainfall to be 1103.20 mm with coefficient of variation (CV) 20.49%. The average value revealed that the study area is receiving sufficient rainfall to favour rainfed agriculture, particularly for crops such as rice, millet, and sorghum which are staple crops cultivated in the area. CV value of 20.49% revealed moderate rainfall variability because values ranging between 20-30% are normally classified in climatological studies as moderate (Toni et al., 2022). The CV value signifies while the rain is not highly unpredictable, occasional dry spell or years of excess rainfall is imminent. The observed rainfall variability has serious effects on agricultural productivity in terms of crop yields, planning of irrigation, and infrastructural development of water storage facilities strategically.
The CV obtained in this research is in line with Awode et al. (2025) who studied rainfall variability in South-Western Nigeria and got a higher inter-annual variations with serious implications on water resources planning and climate change adaptation. The findings also concurs with Tegegne et al. (2025) who established CV of 16-24% for crop water coefficients across different climatic scenarios.
In a rainfed zones like Yauri, where livelihoods are highly sensitive to climate, adaptation and knowledge of rainfall variability are key to food security, economic stability and resilient to climate. The integration of adaptive mechanisms like supplementary irrigation, efficient rain water harvesting and water storage capacity flexibility can cushion the impact of climate variable. Works by Rockström & Barron (2007) and Awode et al., (2025) stresses that incorporating rainfall analysis and in adaptive irrigation planning enhances yield stability, and reduces production risks in semi-arid environments.

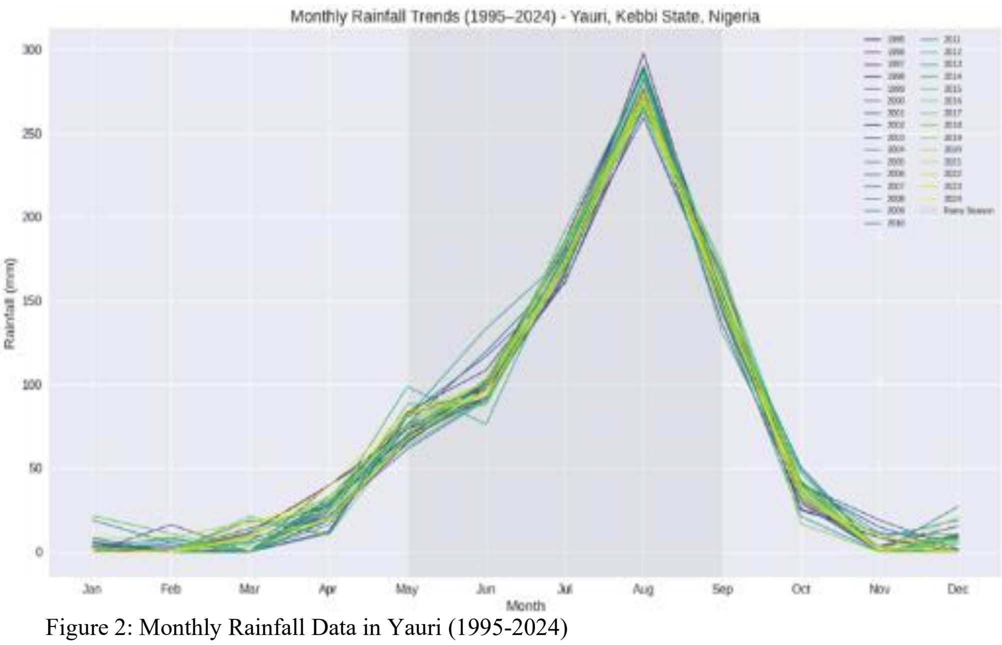

Figure 2: Monthly Rainfall Data in Yauri (1995-2024)

Figure 3 indicates thirty years' (1995-2024) average minimum and maximum monthly temperatures. The analysis of the data showed evident of monthly fluctuations in both minimum and maximum temperatures. January (16.24℃), December (16.55℃) had the lowest minimum averages, while April (26.25℃) and May (25.47℃) had the highest ones. Mid-year months, June to September, possessed comparatively stable values ranging from 22.72℃ to 23.87℃. The corresponding coefficient of variations (CV) ranged from 3.61% in September to 12.16% in December, showing temperature stability variation across the year. For maximum temperatures, the uppermost were in March (39.64℃), April (38.76℃), and February (37.52℃) while the lowest were in August (30.48℃) and July (31.53℃) at the peak of the wet season. The CV for these ranged from 2.05% in September to 3.51% in February, with relatively low inter-annual variability in monthly maximum temperatures. Inter-annual variations in minimum and maximum temperatures are disclosed in coefficient of variations (CV) values. The minimum CVs in minimum temperatures were obtained in September (3.61%), July (4.16%), and August (4.20%), which validate consistent and reliable conditions during wet season. The maximum CVs obtained in December (12.16%), February (10.26%), and November (9.59%) are related to greater variability linked with transitional periods and harmattan impacts, which may affect germination, flowering, and crop water requirements. Maximum temperatures were described as relatively low in variability (CV<5%), with the lowest in September (2.05%) and high in February (3.51%), showing stable thermal conditions across years. Stability is critical for agricultural planning since it allows for suitable temperature regimes during essential crop growth stages. The same pattern of variability has been reported by Akinyemi et al. (2021) who documented low variability in minimum temperature in Ilorin, with CV values ranging from 5.49% to 7.31%. Amadi et al, (2014) also revealed variability in temperature across the country with Northern Nigeria experiences more temperature variability than southern part of the country, while Budnukaeku & Emmanuel, (2024) observed comparable increase in temperature in the dry season. Amankwah, (2023) emphasized that even slight variability in temperature can have impacts on crop yields and may affect agricultural sustainability.

The minimum temperature pattern in Yauri reflect such general climatic trends, with cold nights during the harmattan season (December-February) and hot nights in the rainy seasons (May-September). The low CVs that are experienced during the rainy season indicate uniform nighttime temperatures that are favourable for crops such as rice, maize, and vegetables while higher variability during the dry season poses challenging to planting at an early time and irrigation scheduling, particularly for temperature-sensitive crops such as tomato, rice, and maize.

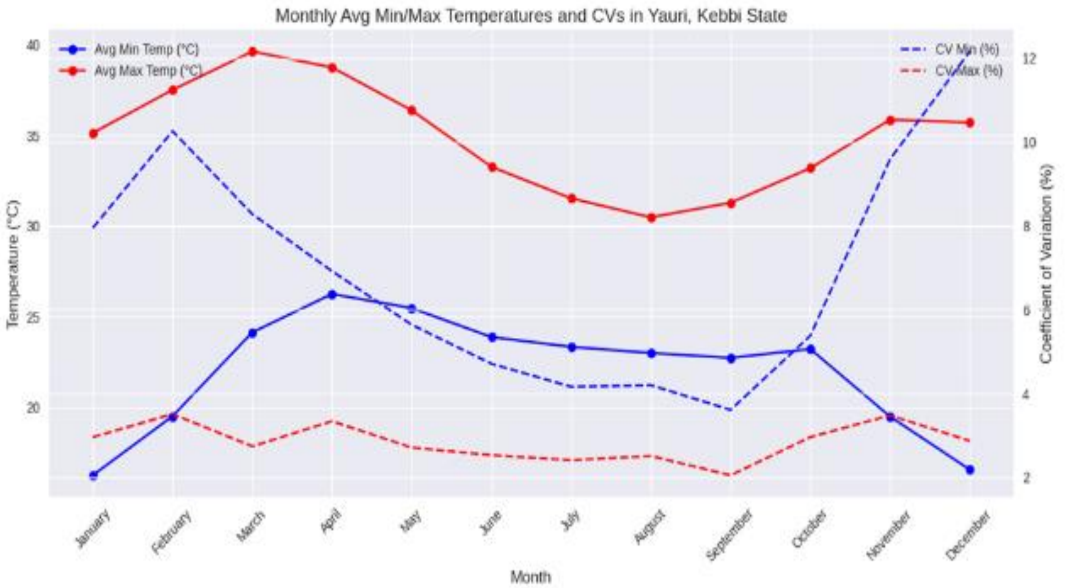

Figure 3: Monthly Average Minimum and Maximum Temperatures in Yauri (1995-2024).

Rainfall Onset and Cessation Analysis

Figure 4 indicates the onset and cessations of rain for the study period (1995-2024). Onset varies between April 6 (2003, 2006) and May 18 (2015) and the cessation varies between September 4 (1998) and October 17 (2002). The average onset period is mid-April to early May while the average cessation is early to mid-October, indicating five to six months of wet season. Onset is the period at which incremental rainfall has added up to the amount that initiate crop establishment (≥20 mm in three to four consecutive days without interruption), while cessation is when an extended period of over 20 days begin. These rates determine the duration of the growing season, which is essential in planning planting and harvesting calendars (Yonah et al., 2023). Research conducted by Salisu et al. (2024) in Kebbi state, revealed a delayed onset of rain and reduced period of rainy season, which is in line with the climatic change trends as observed by Ezeh et al.(2021). Climate variability causes disarray in traditional farming calendar and uncertainty in rainfed agriculture particularly for crops like rice, and maize which are mostly cultivated in the study area. Delayed onset such as 2015, and 2021, reduces yields, while premature cessation, such as in 1998 exposes crops to water stress at a key development phases. Furthermore, the flood-prone nature of Yauri exposes it to extreme vulnerability to extreme rainfall events after late onset, leading to crop loss and community displacement. Implementation of adaptive soil moisture conservation practices such as mulching, tied ridges, zai pits, and minimum tillage can mitigate such climatic uncertainties.

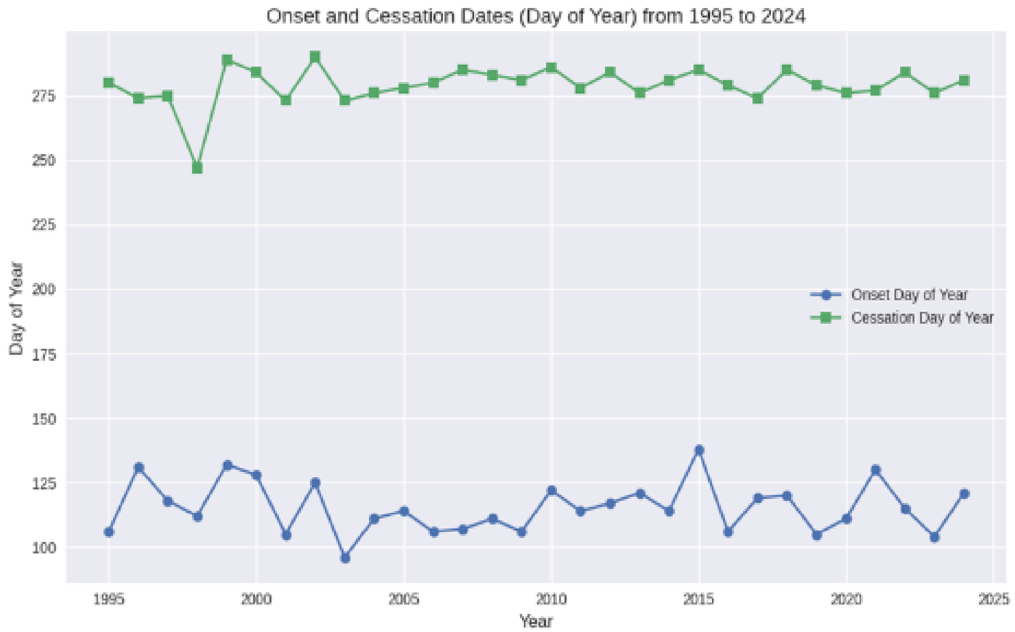

Figure 4: Onset and Cessation period of Rainfall in Yauri (1995-2024)

Temporal Duration of Growing Season

Figure 5 presents the growing season length in Yauri over the period 1995-2024 which shows inter-annual variability across the period of the study. The length of the growing season ranged from 135 days in 1998 to 178 days in 2007, with an average of 164 days and standard deviation of +10.6 days, which is moderate variability. Comparable findings by Igbawua et al. (2023) using a satellite based phenology showed minor extension of season (LOS) across the Nigerian's hot semi-arid (Bhs) areas, like Kebbi state, at a mean rate of +0.2 days per year in the late end and early start. The variability in the length of the growing seasons has a series of agronomic implications: shorter seasons restrict long-term crop production and enhances mid-season drought risks, whereas the longer season may increase postharvest losses through excessive rainfall or flooding. The growing season which was defined as the period between the onset and cessation when soil water and temperature are best for plant growth (Ngetich et al., 2014), regulate water-saving practices, crop suitability, planting dates, and irrigation scheduling. At Yauri, the observed interval of 135-178 days is suitable for medium to long-term crops such as maize, rice, and sorghum, but an early maturing or drought-tolerant cultivars must be grown in a short season (<150 days) and longer season (>170) require double cropping but with very good water management to achieve full yields.

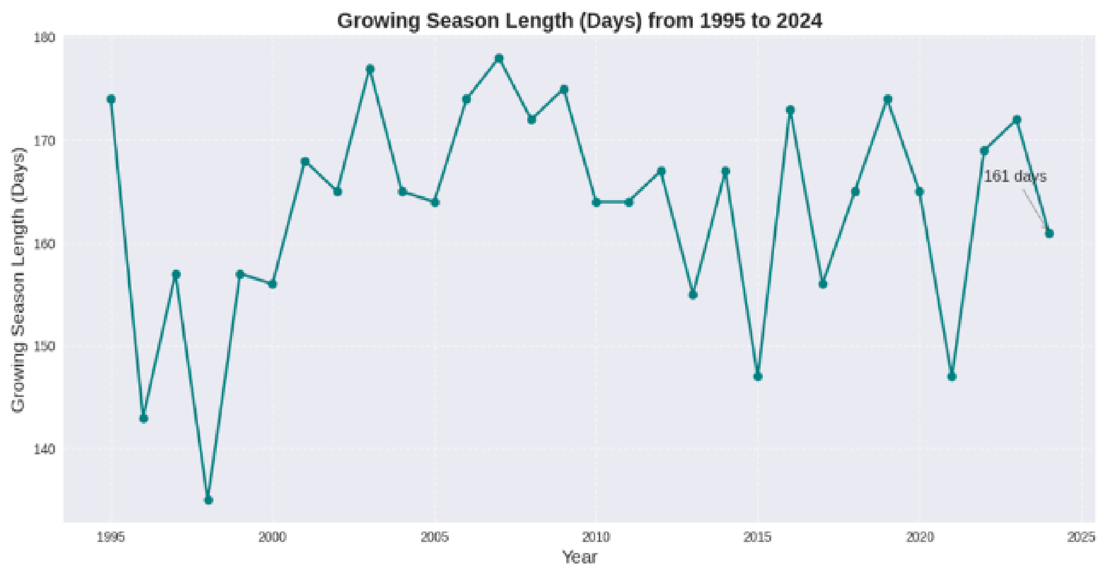

Figure 5: Duration of Growing Season in Yauri (1995-2024)

Quantification of Seasonal Rainfall Amounts

Figure 6 presents the total seasonal rainfall (TSR) during the period 1995-2024. TSR ranged from the minimum of 820 mm in 1996 to maximum of 1913.3 mm in 2022, with a long-term mean of approximately 1100-1200 mm. The notable wet years were 1999 (1564.6 mm), 2018 (1388.8 mm), 2020 (1395.2 mm), and 2022 (1913.3 mm), and high deficit occurred in 1996, 2002, and 2013.

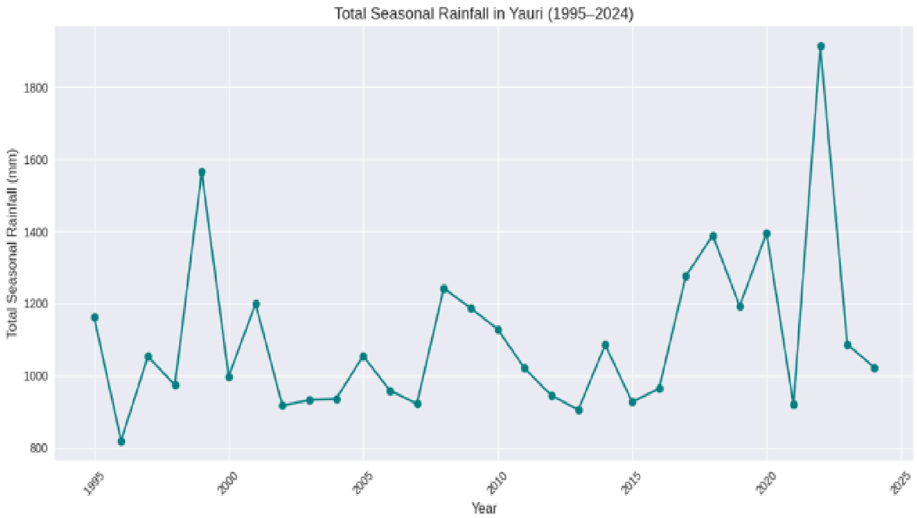

Figure 6: Total Seasonal Rainfall in Yauri (1995-2024)

TSR is the wet-season rainfall each year, typically from April to October in Northern Nigeria. Its uncertainty significantly contributes to determining soil moisture, crop yield potentials, and irrigation needs. Those with rainfall values below 900 mm are water-stressed and adversely impacting water requirements of some crops which are highly sensitive to water such as rice and maize (Ayanlade et al., 2021), whereas TSR above 1300 mm increase the vulnerability to waterlogging, flooding, and nutrient loss in lowland areas (NIMET, 2020). The unusual high TRS in 2022 of 1913.3 mm was simultaneous with overall regional flooding in West Africa (UNDRR, 2023). These findings agree with the works conducted by Odekunle, (2004) and Ayanlade et al., (2021) whose studies revealed rising rain variability and enhanced extreme wet events intensity over the Guinea and Sudan Savanna belts. IPCC AR6 (2021) similarly identifies West Africa as a region of hydrological extremes hotspots, with a rising rainfall intensity and non-uniform seasonal distribution expected. Patterns in TSR directly influence planting season and crop production in Yauri: low rainfall years such as 1996 and 2013 have lower growing season duration and drought stress, while extremely high rainfall years such as in 2022 may likely resulted in flooding of rice fields and fishing communities. These call for integrated water management with flood control, drainage systems, and soil protections combined with drought mitigation through supplemental irrigation, early warning and establishment of resilience crops.

Analysis of Rainfall Distribution Patterns

Figure 7 presents Precipitation Concentration Index (PCI) values for period (1995-2024). PCI values range between 16.30 to 23.81, with majority of the values greater than 18. More than half of the study period (53.33%) had low PCI values (<20), indicating relatively even distribution of rainfall, while 46.67% were in moderate class (20-25), indicating uneven distributions with rainfall concentrated in fewer months. The results show dominant PCI values 18-20, which indicate moderately to highly irregular distribution of rainfall over the region. Years such as 1999 (23.81), 2011 (23.09), and 2017 (23.32) show high concentration of rainfall that is unfavorable for effective water resources management and agricultural planning. According to Botai et al. (2025), PCI values below 10 indicate a uniform rainfall, 10-15 moderate rainfall, 16-20 irregular rainfall, and above 20 highly irregular distribution. The PCI values obtained from the studies are consistent with previous studies by Luis et al., (2011) and Nandargi & K. (2018) who obtained PCI values greater than 16 indicating intense wet-dry season. In Yauri, irregular rainfall demand increased water management through soil moisture conservation, rainwater harvesting, precision irrigation and climate-based agronomic planning.

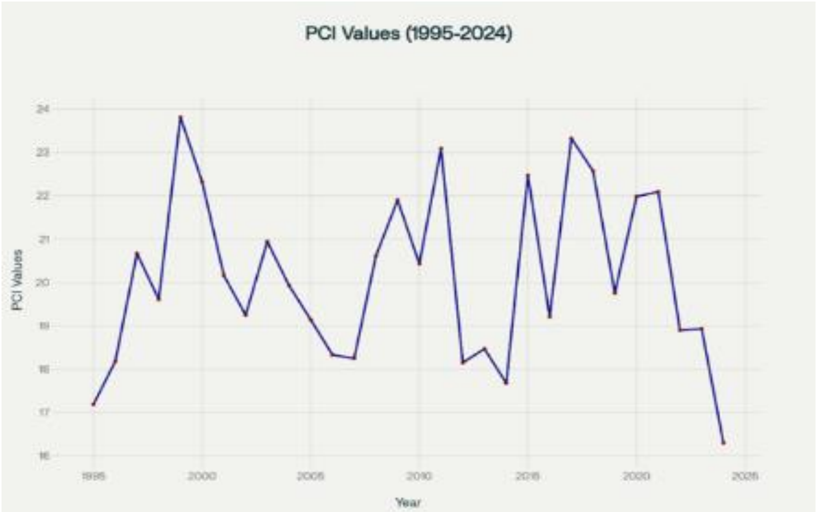

Figure 7: Precipitation Concentration Index (PCI) values for period (1995-2024)

Rainfall Frequency Estimates

Figure 8 presents rainfall frequency estimates for various return periods, derived from 30 years' data (1995-2024), sorted in decreasing order and tested by Weibull's equation. The maximum seasonal rainfall occurred in 2022 (1913.3 mm) with a probability and return period of 3.23% and 31 years respectively, which is very exceptional hydrological event. Some other extreme events are in 1999 (1564.6 mm; 15.5 years), 2020 (1395.2 mm; 10.3 years), and 2018 (1388.8 mm; 7.8 years). Conversely, low instances occurred in 1996 (820 mm), and in 2013 (905.5 mm) with a return period of approximately 1.1 to 1.2 years and therefore occurred frequently. The seasonal rainfall distribution is right-skewed such that majority of the values fall between 900 mm and 1200 mm with rare extremes, that is very wet yeas are rare while moderate to low are frequent. This is what defines semi-arid region regimes which are characteristics of irregularity and susceptibility to extreme events. The 2002 occurrence, with a return period of 31 years, highlight it rarity and possible linkages with exceptional climatic conditions, like an intensified West African Monsoon.

These findings agree with Awode et al. (2025) who reported similar extreme rainfall occurrences in South-Western Nigeria, with a return period of 10-100 years. Agbonaye & Izinyon (2024), also documented increased frequency and intensity of extreme events in Niger Delta, while Ayanlade et al.(2021) recorded reduced wet spells with intermittent high intensity rain similar with 2022 anomaly in Yauri. Comparable rainfall frequency behaviour in West Africa (Nicholson, 2017; IPCC, 2021) supports these conclusion with increasing hydro-climatic extremes forecast based on IPCC AR6. Infrastructures for controlling need to be constructed to be resilient to extreme rain events with return period 10-30 years.

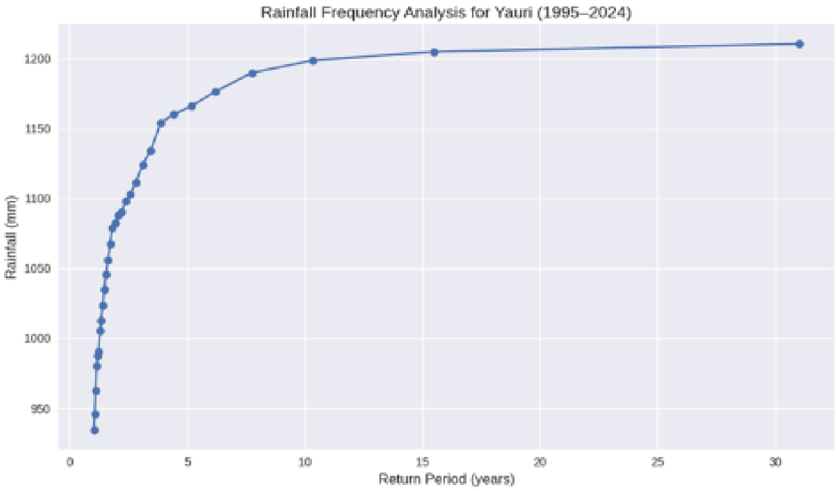

Figure 8: Rainfall Frequency Estimates for various return periods in Yauri

Temperature Anomaly Results

Figure 9 shows the results of the temperature anomaly analysis. Temperate Anomaly Index (TAI) results provide monthly Z-score indicating deviations from long-term monthly means in the history. The results reflect a pattern of alternative positive and negative anomalies with some persistent negative anomalies especially in the mid-year moths (May to August) in several years, and positive anomalies occurring more often at the beginning (January to April) and end (October to December) of the year. The strongest warming signal was felt in January ,2010 and January 2021 with the same value +2.58, and the same holds for April 2024 with a value of +1.46. Conversely, June-September period revealed frequent strong cooling signals with the values of -1.99, -1.13, and -1.08 for June 2014, July 2021, and September 2006, respectively. October registered mixed trends, while October 2006 registered the lowest anomaly at -2.08, and October 2015 at +1.13, a robust warming episode. The findings revealed a clear seasonal trend with a prevailing robust warming for the dry season and cooling or suppressed warming during the wet season. TAI values above +1.0 indicate a robust warming departure while below -1.0 indicate a robust cooling, and around zero indicate a normal. Increases in positive anomalies in dry months reveal rising heat stress, while negative anomalies in wet season reveal an alteration in monsoon dynamics or diminished convective activity.

The temperature anomaly results obtained for this study is consistent with previous studies that have reported rising temperature anomalies in Nigeria and other west African countries (Adekola et al., 2021; Akinnubi et al., 2024). Adekola et al., (2021) reported similar trend under RCP4.5 and RCP8.5 scenario, and Nasara et al. (2025) linked Northern Nigeria's heatwaves to declining rainfall efficiency in response to the cooling in the wet season in this study. Globbally, the IPCC (2021) confirms that West Africa is warming at a faster rate than the global average and this has significant implication to agriculture, water resources, and climate resilience. The intensified warming in this dry months (April to May) can aggravate pre-rainy season drought stress, and decrease wet season anomalies that could change rainfall intensity and distribution. These trends underscore the need for adaptive water management and climate resilience intervention to support agricultural production in the region.

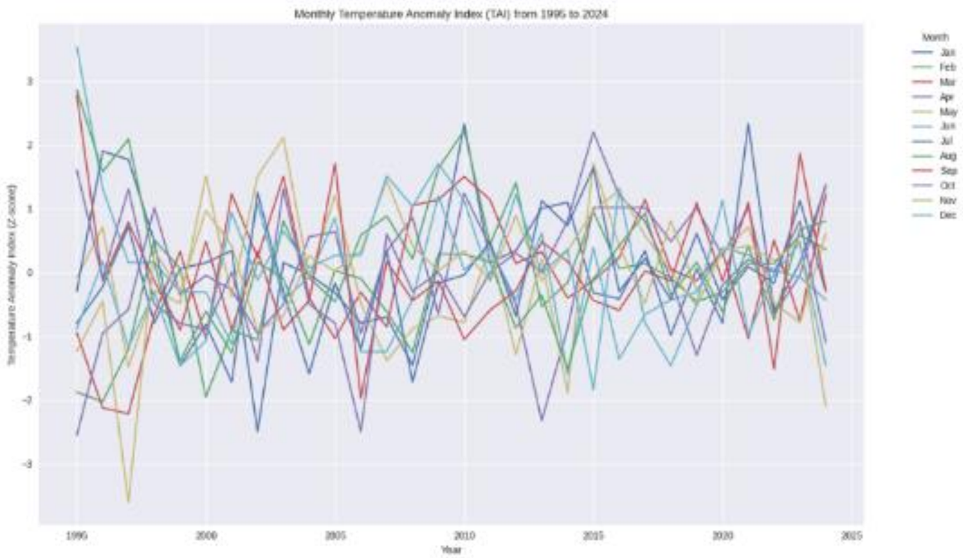

Figure 9: Temperature Anomaly Analysis (1995-2024)

Trends and Magnitudes of Rainfall

Figure 10 displays the rainfall trends over thirty years (1995-2024) as obtained from Mann-Kendall trend analysis of the data. The test produced an S Statistic value of +69, variance of 3141.67, a Z-score value of 1.21, and p-value of 0.225, indicating a weak but statistically insignificant upward trend in seasonal rainfall. The Z-score is below the ± 1.96 threshold at 95% confidence level, confirming the null hypothesis of no overall monotonic trend for MK test. Although, the positive Z-score indicate a slight increase in rainfall over the last decade, the magnitude is too small to exclude natural variability as the dominant factor. The trends in Yauri rainfall agree with Oluwadare & Oluwadare, (2023) who reported a non-significant decline in annual rainfall at Ekoli-Ekiti. Ishaku et al. (2024) also observed significant increases in at Gombe and Mubi but decreases at Maiduguri and Yola, indicating a marked heterogeneity in rainfall patterns. The weak upward trend in Yauri likely reflects inter-annual variability rather than persistent climatic shift. The occurrence of heavy rainfalls in years 1999, 2020, and 2022 suggest sporadic intensification rather than steady long-term increase, which is undermine rainfed agriculture which rely on predictable rainfall cycles.

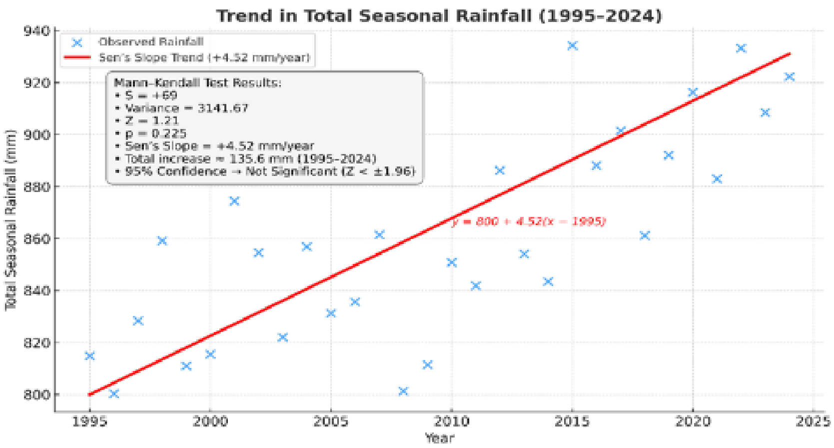

Figure 10: Trend and Magnitude in Total Seasonal Rainfall (1995-2024)

Sen's slope Estimator revealed a positive trend of $+4.52\ mm\ year^{-1}$, representing an overall increase of about 135.6 mm over the period of the study, consistent with the Mann-Kendall weak upward tendency. Although, modest, this rise is significant in Yauri's semi-arid environment where a small change in precipitation can greatly impact water resources and crop productivity. The increase in seasonal rainfall although for agriculture but can also contribute to flooding and soil erosion hazards. Incorporating climate analytics into planning, constructing water storage infrastructures, and simulating adaptive farming practices will facilitate the utilization of these changes while preventing associated risks.

Trends and Magnitudes of Temperatures

Figure 11 presents comparative trends analysis of minimum and maximum variations over the period under consideration. The test for average minimum annual temperature trend shows statistically significant warming trend. The MK test returned an S-statistic of 274, variance of 3140.6, Z-score of 4.87, and a p-value of 1.11×10^{-6}, much lower than 0.05, thereby rejecting the null hypothesis of no trend. Sen's slope Estimator showed a warming rate of $+0.074\ ℃\ year^{-1}$, suggesting an overall increase by about 2.22 ℃ in the past three decades. Statistical trend for the minimum temperature for the whole period of study, suggests diminished nocturnal cooling with tremendous implications for agricultural system and water resources of the region. Warming was more pronounced in monthly at the monthly timescale from March to October, with the March showing steep slope of 0.15 ℃ $year^{-1}$. In contrast, January, February, and December have no statistically significant trends. The positively consistent S-statistic and large Z-score confirm monotonic increasing trend in minimum temperatures, with the Sen's slope estimating the rate of increase. Similar observations were made by Frimpong et al. (2022) in Accra, and Kumasi in Ghana, and Muia et al, (2024) in counties of Kenya with 0.05 to 1.2 ℃ $year^{-1}$gradients. These findings are also similar with the IPCC (2023) report which observed increasing minimum temperatures as general indicator of tropical climate change. The interlocking of evidence indicates that warming trend seen in Yauri is representative of extensive large-scale regional climatic tendency.

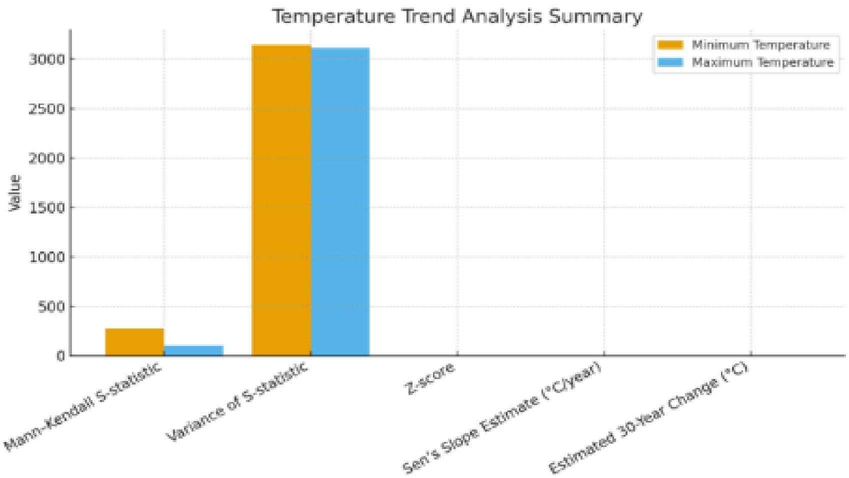

Figure 11: Trend Analysis of Minimum and Maximum Temperature Variations

For maximum temperatures, the findings indicated a weaker but increasing trends. The Mann-Kendall and Sen's slope tests indicate a moderate but consistent warming in Yauri's maximum temperature series. Although, the overall annual trend (Z=1.81, p=0.073; slope =+0.0346 ℃ $year^{-1}$) is not statistically significant at 5% but there is significant monthly warming in February (p=0.047; slope=+0.067 ℃ $year^{-1}$), and April (p=0.021; slope =+0.059 ℃ $year^{-1}$), reflecting a rising pre-rainy season heat. This trend of climatic warming is consistent with Oguntunde et al. (2011) who reported a rise of the maximum temperature in Sahel region, and with Alhaji et al. (2018), and Oderinde et al. (2022), who documented anthropogenic-drive in temperature and exacerbation of extreme heat in Northern, Nigeria. Furthermore, the record of February, and April warming is reminiscent of pre-monsoon heat build-up as identified by Onyejuruwa et al., (2025), which emphasizes potential consequences on early-season evapotranspiration stress and crop vulnerability in semi-arid areas. The concurrent rise in both minimum and maximum temperatures poses significant problem in agricultural water management in Yauri. Warmer nights decrease cooling essential for crop recovery, aggravating heat stress, while higher daytime temperature increase evapotranspiration and crop water requirements. These temperatures changes may shorten the growing periods and intensify water stress in their most productive growth phases, affecting the crop yields. These impacts can be minimized by adopting climate-smart strategies like precise irrigation scheduling, water-use efficient systems (drip and sprinkler), heat-tolerant crop varieties, adjusting planting calendars.

Crop Water Requirement

Figure 12 shows the results of crop water requirements (ETc) for rice, millet, and sorghum for the study period from 1995 to 2024. Rice ETc ranged from 855.5 mm to 920.3 mm in 2021, with over increasing trend, particularly after year 2000. These values are within the range of reported seasonal water requirements for rice in semi-arid to sub-humid tropical climate, typically from 800 mm to 1200 mm per season (Macauley, 2015; FAO, 2021). Millet ETc varied from 315.3 mm in 1996 and 331.1 mm in 2003, with a moderate inter-annual variability. Sorghum ETc varied between 381.4 mm in 2004 and 392.0 mm in 2003, and fairly stable during the last decade. Reported ranges for millet (300-450 mm) and sorghum (slightly higher) are in agreement with the ETc values obtained in this study (Gohil, 2023).

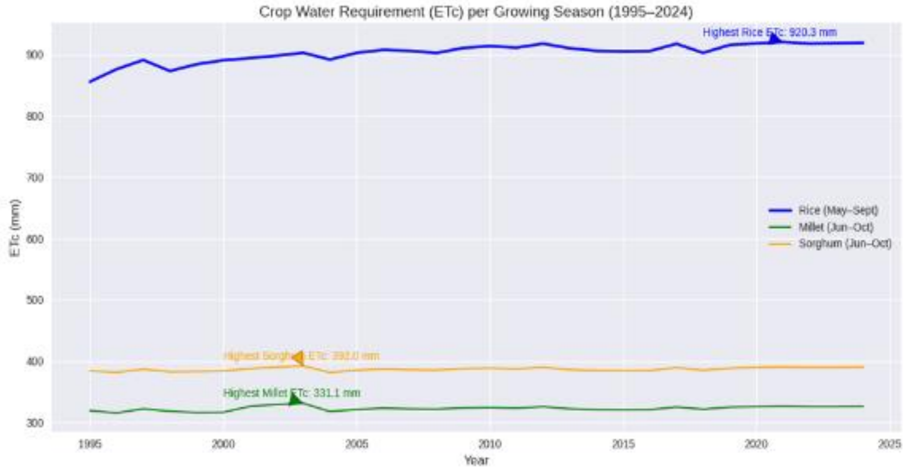

Figure 12: Crop Water Requirements for Rice, Millet, and Sorghum in Yauri (1995-2024)

The rice high's ETc values emphasizes its high-water demand, particularly at mid-growth stage when the crop coefficient (Kc) is at its peak 1.2. Both millet and sorghum have lower Kc values and shorter growing periods, thus lower evapotranspiration demands. The long-term 30-years increasing trend in ETc, most pronounced in rice (+64.8 mm), shows the effects of rising temperature and solar radiation on crop water use. The lower ETc for millet and sorghum attest to their drought tolerance. However, increasing trends in all crops indicate escalating water stress and justifies the necessity for effective irrigation management and climate-resilient cropping practices to sustain effective agricultural water management in Yauri.

Field Survey Results on Agricultural Water Management Practices

Figure 13 presents the findings of agricultural water management practices among farmers in Yauri. Most respondents (74.07%) cultivate 1 to 2 hectares of land, which is indicative of the prevalence of smalls-scale farming systems. About 14.81% of the sample, cultivable less than 1 hectare, while the medium-scale farms (2-5 hectares) constitute 8.47%. Only 2.65% of the farmers cultivate more than 5 hectares of lands, indicating a small-scale commercial farming in the region. The main source of water for irrigation is the groundwater, as the 84.66% of the farmers rely on it, whereas 15.34% are using surface water such as rivers and ponds for irrigation. Surprisingly, none of the respondents utilized rainwater as the main source of water for irrigation, although the region experiences seasonal rainfall. In terms of water supply reliability, 44.44% of the farmers enjoy year-round consistent supply, 22.22% enjoy seasonal supply, and 33.33% have unreliable supplies with grave risks to crop yields and food security.

Irrigation practice is largely traditional. A vast majority of the respondents (91.53%) utilize surface irrigation systems such as furrow, basin, or flood systems. Just 5.82% utilize drip irrigation and 2.65 utilize sprinkler systems, indicating the low adoption level of modern water-conserving technologies. Monitoring efficiency of irrigation system is also low: 55.56% of the farmers do not have any means of assessing irrigation performance. While 33.33% check for leaks or runoff, only 11.11% use flow meter, and none of them reported using soil moisture sensor or automatic systems. Water loss is persistent challenge with 59.79% of the respondents having periodic leakages, 17.99% have regular losses, and only 22.22% reported no losses in their systems. Likewise, water-reuse is also underdeveloped: 59.79% never reuse water, 30.16% do it occasionally, and only 10.05% recycle water in their farms.

Irrigation scheduling is fixed and periodic to a great extent. Most of the farmers (74.60%) irrigate 2-3 times a week, 14.81% irrigate twice weekly, and 10.58% everyday, reflecting little flexibility based on crop or soil moisture. However, drainage management appear to be more proactive with 66.14% utilize retention ponds, 39.15% construct drainage channels, 28.04% implement terracing, 22.22% plant cover crops, and 15.87% implement mulching to minimise runoff. Soil moisture conservation is practised by majority: 63.49% practice organic matter such as compost or manure, 35.45% practised contour farming, and 27.51 % practice mulching. However, 35.98% of the farmers do not adopt any conservation method, indicating a scope for improvement in the sustainable management of the soil.

Water storage structures are in poor conditions. Majority of the respondents (83.07%) do not have water storage systems, while 10.58% have small capacity (5,000-10,000 litres), and only 6.35% have good storage systems (>20,000 litres). Energy for irrigation is predominantly derived from diesel and petrol generators (90.48%), while the solar energy is utilized by only 9.52%. There were no cases of utilization of grid electricity, wind or manual systems by the respondents, which indicate the energy constraints of the farmers. Technology adoption remain low as manual methods dominate the systems (94.18%), while only 5.82% of farmers use plain technologies such as timers and flow meter. Complex systems such as automated irrigation or sensor- controlled irrigation systems are entirely absent. Under climate adaptation, 56.08% of the respondents have changed crop varieties, 50.26% have adjusted planting dates, and 28.04% use mulching. Despite its potential to ease seasonal water deficiency, rainwater harvesting is only practiced by 9.52% of the farmers.

Policy awareness is fragmented with 22.22% of the respondents following government's guidelines and advice on water management, while 25.40% are aware but not following, and 43.92% are entirely unaware, indicating the need for more awareness and education. Farmers reported strong demand for support: 50.79% seek improve irrigation facilities, 40.03% request training in water-saving practices, and 28.57% need technical advice and extension services. The findings of the survey indicate an agricultural system constrained by poor infrastructures, low technology coverage, high input cost leading to inefficient use of water. Surface irrigation at an efficiency of 30-40% (Jain et al., 2023) result in huge loss of water through evaporation and percolation. Farmers' dependence on petrol-powered pumps and limited storage capacity may aggravate vulnerability to energy prices uncertainty and seasonal water shortages. These are the characteristics of inadequate institutional support and limited access to credit facilities which are consistent with Oyebode, (2024), who identified high cost of inputs and inefficient extension services as barriers to irrigation modernizations. The low utilization of flow meters and soil moisture devices further indicate low awareness of precision irrigation, and this is in line with the works of Aduramigba-Modupe & Oke, (2023), who reported that less than 10% of the Nigerian small-scale farmers use data-driven irrigation scheduling.

Despite all these challenges, new adaptive measures such as mulching, organic amendment, and the use of resistant crop varieties indicate a growing awareness of climatic resilience among farmers. However, the wide spread adoption of these measures are constrained by weak institutional policies and lack of infrastructural facilities. These trends are being witnessed across the broader Sahel and Northwestern, Nigeria, where increased in climate variability are prompting a gradual shift towards groundwater-based irrigation (Awode et al., 2025; Saidu et al., 2024). In Yauri, the absence of incentive for investment and enabling institutional frameworks is maintaining dependence on traditional, fuel-based irrigation. These findings are in agreement with the works of Abubakar et al, (2024), who highlighted limited access to credit facilities and ineffective extension services as great barriers to technology diffusion and sustainable water management for the Sudano-Sahelian belt.

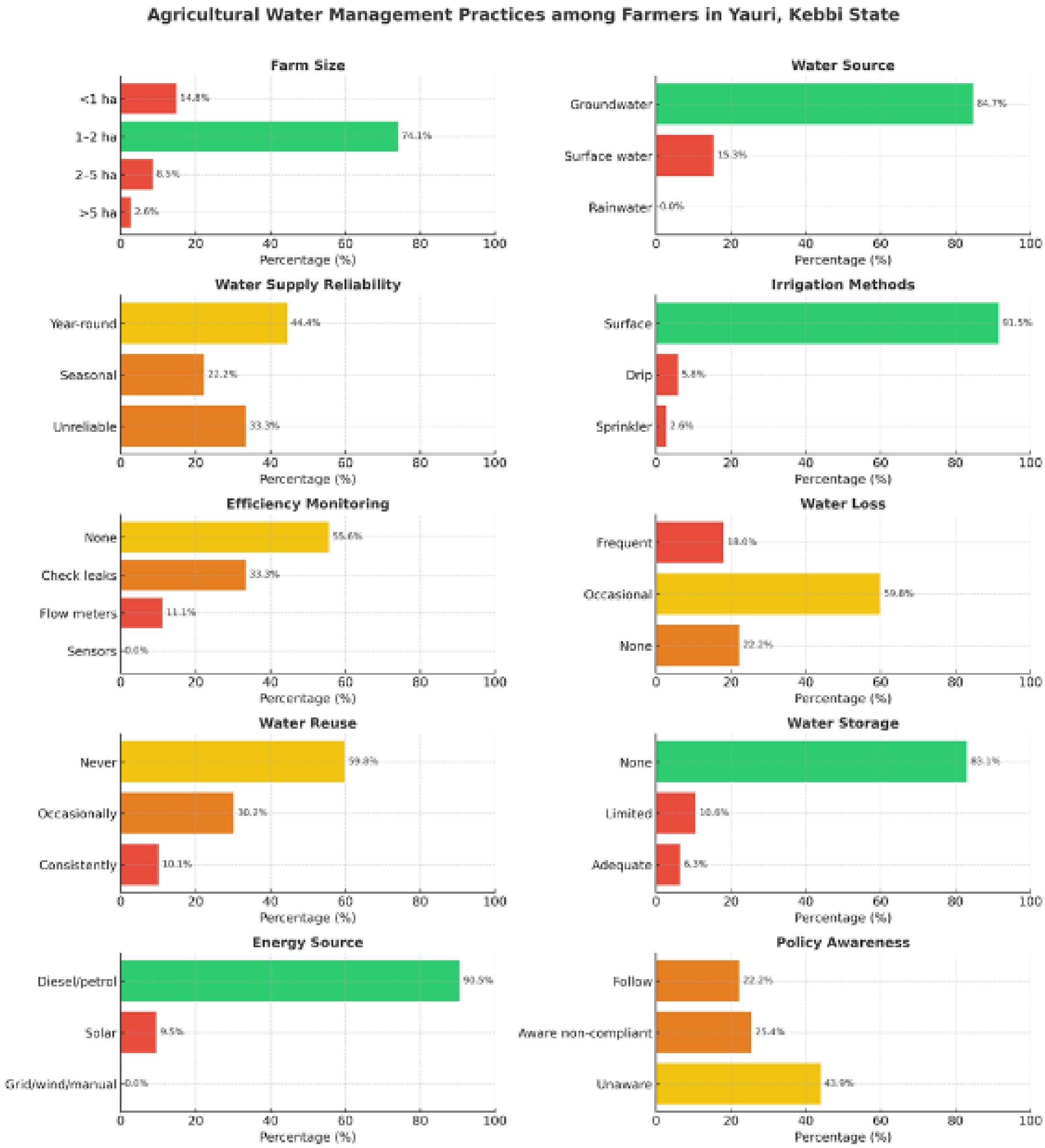

Figure 13: Agricultural Water Management Practices among Farmers in Yauri

Figure 14 present summary of the study's finding, corresponding recommendations and the expected benefits of implementing the measures in Yauri, Northwestern Nigeria. The flowchart illustrates the inter-linkages between climate variability, agricultural water management problem and the proposed adaptive strategies, noting their contribution towards increases water security, resource efficiency, and agricultural resilience. This chart is helpful roadmap to applying empirical information to create efficient policies and sustainable management methods in rainfed agroecosystem.

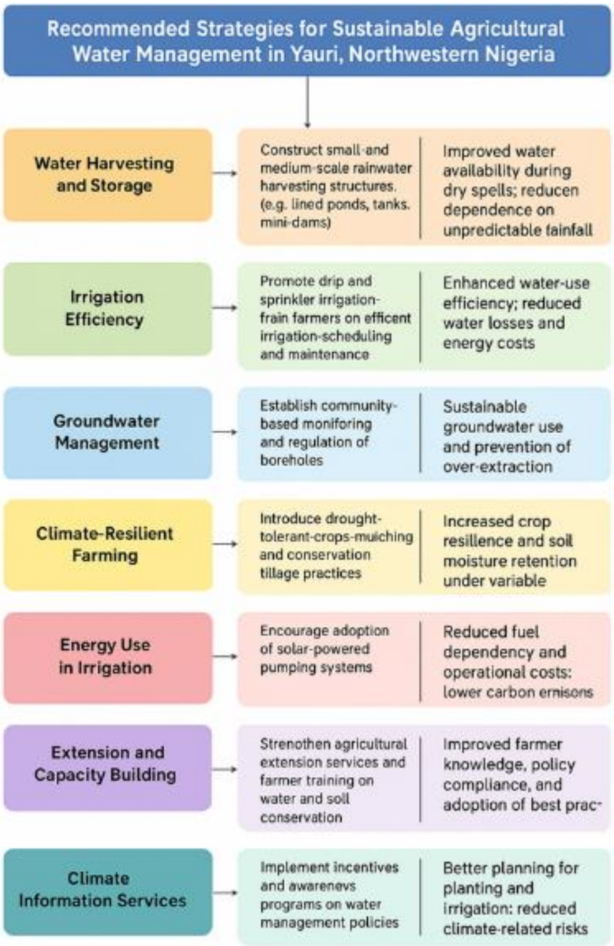

Figure 14: Summary of the Study's findings, corresponding recommendations and the expected benefits

CONCLUSION

A three-decade (1994-2024) time series analysis of climatological and agricultural water management, reveals a generally variable but satisfactory climate for rainfed production of the major crops such as rice, millet, and sorghum. The mean annual rainfall of 1103.20 mm with coefficient of variation of 20.49% indicate adequate but irregular rainfall, and a wet season that usually lasts between five to six months. Although, rainfall had a slight, insignificant positive trend ($+4.52\,℃\,year^{-1}$), minimum temperature rose significantly ($+0.074\,℃\,year^{-1}$), and maximum temperature rose slightly ($0.0346\,℃\,year^{-1}$), reflecting broader regional trend toward warming. Rainfall onset and cessation lie between mid-April and mid-October, providing an average growing season of 164 days, though inter-annual variability still exist. Rainfall distribution analysis showed moderate irregularity with periodic rainfall concentration that tend to restrict water availability and complicate crop production. Exceptionally wet years such as 1999 and 2022 were relatively rare at return periods of around 15.5 and 31 years, respectively. Dry-season warming and wet-season cooling were the dominant thermal patterns as reflected by the Temperature Anomaly Index. The results of Agricultural water management surveys indicate that Yauri is dominated by small-scale farmers relying on groundwater and traditional surface irrigation system. Adoption of efficient, water-saving technologies remain low because of limited storage capacity, inefficient water application, and absence of irrigation scheduling in accordance with crop water requirement. In addition, awareness of applicable agricultural water management polices is weak. Nonetheless, there is strong farmers interest for improved irrigation technologies, capacity building, and technical support. Overall, the findings reveal a gradually warming climate, moderate rainfall variability and low technical adoption by the farmers. Improving climate-resilient agricultural practices, promoting water-conserving technologies, upgrading irrigation and storage facilities, and improving policy communication, and farmers training are essential measures to ensure maximum resilience and sustain agricultural productivity under evolving climatic condition

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