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Estimation of Water Requirement for Rice Production Using Penman's Equation in Central Cross River State, Nigeria

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Abstract **Original Research Article**

This study estimates the water requirements for rice cultivation in Central Cross River State, Nigeria, using Penman's equation to derive reference evapotranspiration (ETo) based on climatic data spanning 42 years (1981–2022). The research focuses on Ikom Local Government Area, characterized by a humid tropical climate with bimodal rainfall patterns conducive to rice production. Climatic parameters, including temperature, humidity, wind speed, and sunshine hours, were collected and processed to compute ETo and crop evapotranspiration (ETcrop) across different growth stages of rice. The findings indicate an average annual rainfall of approximately 2174.47 mm, with peak rainfall during July to October, aligning with the main rainy season. The estimated water requirements for rice ranged from [insert specific values], varying across crop stages, emphasizing the importance of tailored irrigation scheduling. The application of Penman's equation demonstrated its utility in providing localized water demand estimates, which are vital for optimizing water management and enhancing rice productivity under changing climatic conditions. This research offers critical insights for policymakers and farmers seeking sustainable water resource utilization, contributing to climate-resilient rice production strategies in Nigeria's humid tropical regions.

Keywords: Rice Cultivation, Water Requirements, Central Cross River State, Penman's Equation, Reference Evapotranspiration, Climatic Data, Ikom Local Government Area, Humid Tropical Climate, Bimodal Rainfall, Temperature, Humidity.

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1. INTRODUCTION:

Rice (*Oryza sativa*) is a critical staple food, providing nourishment for over half of the world's population, particularly in Asia and Africa (FAO, 2020). In Nigeria, rice consumption has steadily increased over the years, driven by population growth, urbanization, and changing dietary preferences, making it a vital crop for food security and economic development (Akinbile and Akinbile, 2019). Central Cross River State, located in southeastern Nigeria, is an important rice-producing region with a significant contribution to the country's rice supply chain.

Despite its importance, rice cultivation in Nigeria faces several challenges, notably water scarcity and inefficient water management practices (Adewumi *et al.*, 2021). Water availability remains a critical factor influencing rice yields, especially in regions prone to seasonal variability in rainfall. Efficient water resource management is essential to optimize rice production while conserving water, which is increasingly under pressure due to climate change and population growth (FAO, 2020).

Understanding the water requirements for rice cultivation is therefore crucial for planning and sustainable management. Water needs in rice production are primarily driven by evapotranspiration, which accounts for the loss of water through evaporation and transpiration from the crop (Allen *et al.*, 1998). Accurate estimation of crop water requirements helps farmers and policymakers develop effective irrigation schedules, reduce water wastage, and improve overall productivity.

Despite the importance of water management in rice cultivation, there is a lack of localized data on the specific water requirements in Central Cross River State. Existing estimates are often generalized or based on regional data that may not accurately reflect local climatic and agronomic conditions. This gap hampers effective planning and resource allocation.

Furthermore, there is a need for precise and reliable estimation tools to determine crop water requirements under specific regional conditions. Penman's equation, a widely recognized method for estimating reference evapotranspiration (ET_o), offers a robust approach to derive water needs based on climatic variables (Penman, 1948). However, its application in the Nigerian context, particularly for rice in Central Cross River State, remains underexplored.

This study aims to bridge this knowledge gap by: Estimating the crop water requirements for rice in Central Cross River State using Penman's equation, Assessing the potential water demand for rice cultivation in the region based on climatic data and crop growth stages.

The findings from this research will contribute significantly to sustainable water resource management in the region. By providing localized estimates of water requirements, the study will support farmers and policymakers in developing informed irrigation strategies, optimizing water use, and enhancing rice productivity.

Moreover, the application of Penman's equation in this context will demonstrate its utility as a practical tool for regional water management planning, aligning with global efforts to promote climate-resilient agriculture and water conservation.

2.0 MATERIALS AND METHODS:

2.1 Study Area Description:

Ikom Local Government Area (LGA) is situated in the southeastern part of Nigeria within Cross River State. It lies approximately between latitudes 5.9624°N and longitudes 8.709°E, with an elevation of about 116.85 meters above sea level (Federal Ministry of Works, Nigeria, 2010). The area covers a diverse ecological zone characterized by tropical rainforest vegetation, which supports a variety of flora and fauna, and provides a suitable environment for agriculture.

The climate of Ikom LGA is classified as humid tropical, with a significant amount of annual rainfall distributed throughout the year, peaking between May and October. The decadal average rainfall for the area from 1981 to 2022 ranges from approximately 12.62 mm in January to a maximum of about 336.03 mm in October, indicating a high moisture regime conducive to crop cultivation, especially rice (NIMET, 2022).

Temperature records show mean maximum temperatures generally ranging from 27.62°C to 31.42°C, with mean minimum temperatures between 19.89°C and 23.21°C, reflecting the warm tropical climate typical of the region (NIMET, 2022). Relative humidity levels are high year-round, averaging around 73% to 90%, further supporting the humid environment (NIMET, 2022). Wind speeds are moderate, with average maximum values around 2.44–3.14 m/s, influencing evapotranspiration rates in the area (NIMET, 2022).

The geographical setting and climatic conditions of Ikom LGA make it an ideal location for studying water requirements for rice cultivation, considering the variations in rainfall, temperature, humidity, and wind speed over the decades. The agricultural calendar is largely dictated by the bimodal rainfall pattern characteristic of the region. This climatic pattern typically results in two distinct rice-growing seasons per year. The first, often referred to as the main or major season, coincides with the beginning of the first rainy period, which generally spans from April to September. During this time, farmers take advantage of the abundant rainfall to cultivate rice crops, often utilizing floodplain and lowland areas that are naturally irrigated (Ojo & Oladipo, 2019). The second season, known as the minor or dry season, usually occurs from October to December, corresponding with the short dry spell or the tail end of the rainy season, when irrigation or residual water sources support continued cultivation (Ojo and Oladipo, 2019). This bimodal cropping system allows farmers in Ikom to maximize land use and crop productivity within a single year. The existence of two rice seasons aligns with findings from regional agricultural studies, which highlight the significance of rainfall distribution and water management in determining planting schedules (Ojo and Oladipo, 2019). Understanding these seasonal patterns is crucial for designing appropriate research methodologies and ensuring the accuracy of data collection related to rice farming practices in the area.

2.2 Data Collection and Processing:

Daily climatic weather data for Rainfall (mm), Relative Humidity (2m), Wind speed at 2M (Max and Min), Temperature °c (Max and Min) from 1981-2022 were sourced from https://globalweather.tamu.edu/ and processed in excel 2007 to monthly means. Sunshine hours (h/day), U_{day} (m/s) and U_{night} (m/s) were calculated using:

Angström-Prescott Equation to estimate the sunshine hours

The classic formula is:

$$\frac{S}{S_{max}} = a + b\,(n/N) \quad \ldots\ldots 1$$

Where:

S = *actual sunshine hours*
S_{max} = *maximum possible sunshine hours (day length)*
n = *sunshine duration*

N = *daylight hours (day length)*
a, b = *empirical coefficients (site-specific).* Angström, A. (1924).

*Estimating Sunshine Hours (**U_{day}** and **U_{night}**):*
***U-day**: Daytime sunshine hours, estimated as S*
U-night**: Nighttime hours, calculated as **N - S

2.3. Reference Evapotranspiration (ET_o):

Using Penman's Equation:

$$ET_o = c * [W * Rn + (1 - W) * f(u) * (ea - ed)] \quad \ldots\ldots 2$$

Where:

- *Rn*: Net radiation (from sunshine hours and temperature)
- *W*: Slope of vapor pressure curve
- *f(u)*: Wind speed
- *ea*: Actual vapor pressure
- *ed*: Dew point vapor pressure
- *c*: Constant (depends on units)

2.4 Crop coefficient (K_c)

Crop coefficient (K_c) was determine taking into consideration the different stages of the crop as tabulated:

Stage	Kc Range	Selected Kc	Duration (months)
Initial	1.1-1.15	1.125	0.7 (≈1month)
Crop development	1.1-1.5	1.3	0.6 (≈1month)
Mid-season	1.1-1.3	1.2	2 (≈2months)
Late season	0.95-1.05	1.0	1 (≈ month)
At harvest	0.95-1.05	1.0	0.2 (≈0.2month)
Total	-	-	5.5 months

2.4 Crop Evapotranspiration (ET_o):

$$ET_{crop} = K_c * ET_o \quad \ldots\ldots 3$$

Where:

- K_c: *crop coefficient for each phase*
- ET_o: *reference evapotranspiration*

2.5 Effective rainfall

Effective rainfall (ER) was determined by multiplying the total rainfall by the efficiency factor

$$ER = TR * EF \quad \ldots\ldots 4$$

Where

ER = Effective Rainfall
TR = Total Rainfall the monthly rainfall measured in mm
EF = Efficiency Factor typically 0.70(or 70%), representing the proportion of rainfall that effectively contributes to soil moisture for crops (FAO, 2009).

3.0 RESULTS AND DISCUSSION:

3.1 Climatic trends over 42 years in the study area.

The climatic data for Ikom over a 42-year period (1981–2022) as shown in **Table 1**. reveal significant seasonal and annual variations that have critical implications for environmental, agricultural, and climatic studies in the region. The comprehensive dataset Table 1. encompasses key meteorological parameters such as rainfall, relative humidity, wind speed, temperature, sunshine hours, and wind velocity during day and night, providing a robust basis for understanding local climate dynamics.

3.1.1. Precipitation Patterns and Hydrological Implications

The data exhibit a marked seasonal variation in rainfall, with the total annual rainfall averaging approximately 2174.47 mm. Notably, the months of July, August, September, and October record the highest monthly totals, with September reaching a peak of 306.97 mm, indicative of a pronounced wet season aligned with the typical tropical monsoon climate. Conversely, December and January experience minimal rainfall, registering averages of 9.40 mm and 12.62 mm, respectively, characteristic of the dry season (Ojo *et al*., 2020). This bimodal distribution underscores the necessity for effective water resource management, especially in agriculture and urban planning, as the region experiences distinct wet and dry periods that influence soil moisture availability, groundwater recharge, and hydrological cycles.

3.1.2. Temperature Dynamics and Climate Variability

The mean maximum temperature hovers around 29.21°C, with a slight increase during the dry months (January, February) and peak temperatures observed in September (approximately 27.96°C). The minimum temperatures fluctuate between 19.89°C (January) and 22.61°C (October), reflecting the region's generally warm and humid tropical climate. Such temperature stability, coupled with high humidity levels exceeding 70% during most months, potentially fosters conducive conditions for tropical diseases and affects crop phenology (Adejuwon & Oladipo, 2021). The relatively narrow temperature range suggests a climate that supports year-round agriculture but also underscores the importance of heat and humidity management in minimizing heat stress on crops and livestock.

3.1.3. Relative Humidity and Its Ecological Significance

Relative humidity remains consistently high, averaging approximately 85%, with peaks exceeding 90% during the wet months. These conditions favor lush vegetation and biodiversity but may also promote the proliferation of moisture-loving pests and plant diseases, which can impact agricultural productivity and forest health (Akinbami *et al*., 2019). The high humidity levels are also implicated in the regional microclimate, influencing local weather patterns such as cloud formation and precipitation.

3.1.4. Wind Speed and Energy Potential

Average wind speeds at 2 meters height are modest, with mean values around 1.33 m/s, and slightly higher during the daytime (mean U-day 6.52 ms^{-1}) compared to nighttime (mean U-night 1.33 ms^{-1}). These findings suggest limited potential for wind energy generation but are significant in understanding local ventilation and dispersion of pollutants (Adewuyi *et al*., 2019). The diurnal variation in wind speed could influence microclimatic conditions, affecting evapotranspiration rates and local weather phenomena.

3.1.5. Sunshine Hours and Solar Energy Prospects

The average daily sunshine duration is approximately 350.50 hours annually, with the highest sunshine hours recorded in the dry season (October to December). This high level of insolation underscores the region's potential for solar energy harnessing, which could be pivotal in sustainable energy development and reducing reliance on fossil fuels (Ogunleye *et al*., 2020). The seasonal variation in sunshine hours also impacts agricultural practices, especially crop selection and irrigation scheduling.

3.1.6. Implications and Future Directions

The results collectively highlight the region's tropical monsoon climate characterized by distinct wet and dry seasons, high humidity, and moderate wind speeds. These climatic features necessitate adaptive strategies in agriculture, urban planning, and disaster risk management. For instance, crop varieties resilient to high humidity and heavy rainfall should be prioritized, and water harvesting techniques could be optimized to mitigate dry season shortages. Moreover, understanding wind and sunshine patterns offers opportunities for renewable energy investments, particularly solar power. The high inter-annual variability also warrants ongoing climate monitoring to anticipate and adapt to potential climate change impacts, such as altered rainfall patterns and temperature regimes (IPCC, 2021).

The 42-year climatic dataset from Ikom provides valuable insights into the local climate system, emphasizing the need for integrated environmental management approaches. It underscores the importance of leveraging climatic data for sustainable development, climate resilience planning, and harnessing renewable energy resources, aligning with global climate adaptation and mitigation goals.

Table 1. Mean climatic data of Ikom over 42 years (from 1981 to 2022).

Month	Rainfall (mm)	Relative Humidity (%)	Wind speed (2M)	Temperature (°C) (2m)	Sunshine hours ($hday^{-1}$)	U-day (ms^{-1})	U-night (ms^{-1})

			Max	Min	Max	Min			
January	12.62	73.01	2.50	0.55	30.47	19.89	6.00	1.25	0.275
February	31.17	74.81	2.64	0.62	31.42	21.44	6.20	1.32	0.31
March	103.23	82.27	2.74	0.79	30.94	23.21	6.50	1.37	0.395
April	188.26	86.70	2.71	0.85	30.12	23.59	6.80	1.36	0.425
May	255.47	88.80	2.58	0.77	29.34	23.46	7.00	1.29	0.385
June	294.67	89.71	2.81	0.83	28.36	22.69	7.10	1.41	0.415
July	268.98	90.32	3.08	0.94	27.62	22.14	7.00	1.54	0.445
August	274.85	90.26	3.12	0.99	27.59	21.98	6.90	1.56	0.495
September	306.97	90.46	3.01	0.93	27.61	22.10	6.50	1.52	0.465
October	336.03	90.70	2.44	0.65	27.96	22.61	6.20	1.22	0.225
November	92.83	85.77	2.02	0.45	29.29	22.18	6.00	1.01	0.202
December	9.40	76.66	2.17	0.44	29.78	20.26	6.00	1.16	0.220
Total	**2174.47**	**1019.46**	**31.81**	**8.80**	**350.50**	**265.55**	**78.20**	**16.01**	**4.26**
Means	**181.21**	**84.96**	**2.65**	**0.73**	**29.21**	**22.13**	**6.52**	**1.33**	**0.35**

3.3. Decadal dynamics in climatic data

The analysis of climatic variables over the four decades from 1981 to 2020 reveals notable patterns and trends that are critical for understanding regional climate dynamics as seen on Table 2. The data on rainfall demonstrates a gradual decline, with the maximum annual rainfall decreasing from 210.42 mm in the 1981–1990 decade to 187.99 mm in the 2011–2020 period. This consistent reduction suggests a possible trend towards drier conditions over the last four decades, which could have significant implications for local agriculture, water resource management, and ecosystem stability. The relative humidity exhibits a relatively stable pattern, maintaining high levels around 85% across all decades, with negligible fluctuations, indicating persistent moisture availability in the atmosphere despite decreasing rainfall. Wind speed at 2 meters height shows minimal variation, with the maximum recorded wind speeds remaining around 2.70 m/s, suggesting that wind dynamics have remained relatively stable over the decades. The temperature data reveals a slight upward trend, with the maximum temperature increasing marginally from 28.71°C in the 1981–1990 decade to 28.80°C in 2011–2020, while the minimum temperature remains relatively constant around 21.70°C to 21.76°C. This subtle increase in maximum temperature indicates the onset of a warming trend, which is consistent with global climate change patterns. Sunshine hours per day exhibit a slight increase, from 28.71 hours in the earliest decade to 28.80 hours in the most recent decade, potentially contributing to the observed temperature rise and influencing local weather patterns. The wind direction components, U-day and U-night, show consistent values across the decades, with mean speeds around 1.78–1.80 ms^{-1} during the day and 0.75–2.67 ms^{-1} at night, respectively. These stable wind patterns suggest that wind direction and speed have not undergone significant shifts, which could be relevant for understanding local airflow and pollutant dispersion dynamics. Overall, the decade-wise analysis underscores a trend towards decreasing rainfall, marginal temperature increases, and stable wind and humidity patterns, highlighting the nuanced changes within the regional climate system. These findings provide valuable insights into long-term climatic variability and can inform adaptive strategies in environmental management and policy formulation.

Table 2. Mean decadal climatic data of Ikom over 4 decades (from 1981-1990 to 2011-2020).

Decade	**Rainfall (mm)**	**Relative Humidity (%)**	**Wind speed (2M)**		**Temperature (°C) (2m)**		**Sunshine hours ($hday^{-1}$)**	**U-day (ms^{-1})**	**U-night (ms^{-1})**
			Max	**Min**	**Max**	**Min**			
1981-1990	210.42	85.17	2.67	0.74	28.71	21.66	1.78	2.67	0.78

1991-2000	204.78	85.25	2.68	0.75	28.74	21.71	1.77	2.68	0.75
2001-2010	197.86	85.01	2.70	0.75	28.80	21.70	1.80	2.70	0.75
2011-2020	187.99	85.01	2.70	0.75	28.80	21.76	1.79	2.70	0.75
Total	**801.05**	**340.52**	**10.74**	**2.99**	**115.05**	**86.82**	**7.14**	**10.75**	**3.03**
Mean	**200.26**	**85.13**	**2.69**	**0.75**	**28.76**	**21.71**	**1.79**	**2.69**	**0.76**
CV	**4.82**	**0.12**	**0.43**	**0.53**	**0.17**	**0.19**	**0.72**	**0.56**	**1.98**

3.4 Seasonal Variability in Water Requirements for Rice Cultivation in Ikom

The analysis of water requirements for rice cultivation in Ikom reveals distinct seasonal patterns influenced by variations in evapotranspiration (ET_0) and rainfall as seen in table 3. During the major season, from April to July, the cumulative reference evapotranspiration (ET_0) totals 584.8 mm, with total rainfall reaching 705 mm. The effective rainfall, calculated as 70% of total rainfall, varies from 132 mm in April to 179 mm in May, 206 mm in June, and 188 mm in July. Notably, in all these months, the total rainfall exceeds the crop's ET_0, resulting in negative or zero irrigation requirements. This indicates that natural precipitation during the major season is sufficient to meet or surpass the crop's water demands, thereby eliminating the need for supplemental irrigation. Such findings underscore the potential for water conservation during this period, as reliance on natural rainfall is adequate for optimal rice growth, which can lead to significant reductions in irrigation costs and water resource utilization.

In contrast, the minor season, from August through October, exhibits a different pattern. The total ET_0 for this period is 427.7 mm, while total rainfall sums up to 642.28 mm. The effective rainfall during these months is 192.4 mm in August, 214.88 mm in September, and 235 mm in October. Despite the high total rainfall, the effective rainfall remains below the crop's ET_0 in October, resulting in an irrigation requirement of approximately 94.22 mm. Interestingly, in August and September, the rainfall again exceeds the crop's ET_0, indicating sufficient natural moisture without supplemental irrigation. However, the shortfall in October highlights the necessity for targeted irrigation to compensate for reduced effective rainfall, ensuring consistent crop growth and yield.

These findings emphasize the importance of seasonal water management strategies tailored to local climatic patterns. During the major season, reliance on natural rainfall can be maximized, reducing irrigation dependencies. Conversely, in the minor season, particularly October, strategic irrigation scheduling becomes critical to fill the water deficit and sustain rice productivity. Implementing such season-specific water management practices can enhance resource efficiency, reduce irrigation costs, and promote sustainable rice cultivation in Ikom. Therefore, understanding and leveraging seasonal rainfall and evapotranspiration dynamics are essential for optimizing water use and ensuring food security in the region.

Table 3: Major and minor seasons water requirement of rice of Ikom.

Month	**Eto (mmday^{-1})**	**Total Eto(mm)**	**Total rainfall (mm)**	**Effective Rainfall (mm)** (70%)	**ER (mm)** (Eto-ER)	**Irrigation Requirement (mm)** (ER-ETcrop)
Major Season						
April	4.8	4.8*30=144	188.26	0.7*188.26=132	144-132=12	132-144=-12 0(no irrigation required)
May	4.8	4.8*31=148.8	255.47	0.7*255.47=179	148.8-179=30.2	0 mm (rainfall exceeds ETcrop)
June	4.8	4.8*30=144	294.67	0.7*294.67=206	144-206=-62	0 mm (rainfall exceeds ETcrop
July	4.8	4.8*31=148.8	268.98	0.7*268.98=188	148.8-188=-39.2	0 mm (rainfall exceeds ETcrop
Total		**584.8**	**1007.38**	**705**		**0**

Minor Season						
August	4.7	4.7*31=145.7	274.85	0.7*274.85=192.4	145.7-192.4=-46.7	0 mm (rainfall exceeds ETcrop
September	4.7	4.7*30=141	306.97	0.7*306.97=214.88	141-214.88=-73.88	0 mm (rainfall exceeds ETcrop
October	4.7	4.7*30=141	336.03	0.7*336.03=235	141-235.22=-94.22	0 mm (rainfall exceeds ETcrop
Total		**427.7**	**917.85**	**642.28**		**0**

3.5 Developmental stages water requirement of rice in Ikom

The estimated water requirements for rice cultivation across various developmental stages in Ikom as determined based on crop coefficients (Kc), duration, and reference evapotranspiration (ET_o) are seen in table 4. The initial growth stage, lasting approximately one month with a Kc of 1.125, required an estimated 101.25 mm of water, reflecting minimal transpiration typical of early vegetative growth. During the subsequent development stage, also lasting one month, the Kc increased to 1.3, and the water requirement rose to approximately 124.8 mm, indicating the increased transpiration as the plants establish their leaf area. The mid-season stage, spanning two months, exhibited the highest cumulative water demand, with a Kc of 1.2 and a total ET_{crop} of around 162 mm; this period likely corresponds to reproductive development and grain filling, which are critical for yield formation. In the late-season phase, with a Kc of 1.0 over one month, the water requirement was estimated at 144 mm, slightly higher than the initial stage, possibly due to increased evapotranspiration rates associated with mature plant physiology. At harvest, a brief period of approximately 0.2 months, the water demand was estimated at about 120 mm, representing the residual water needs as the crop completes maturation. These findings underscore the importance of implementing stage-specific irrigation schedules to optimize water use efficiency. The mid-season stage, in particular, necessitates careful resource planning due to its higher water demand, which is vital for maintaining crop health and maximizing yield. While these estimates provide valuable insights, they are based on average climatic data and crop coefficients; future research should incorporate localized climatic variability and soil moisture dynamics to refine irrigation management strategies further.

Table 4: Estimated rice developmental stages water requirement for Ikom locality

Stage	Kc	Duration(months)	Avg. ET_o ($mmday^{-1}$)	Monthly ET_{crop} (mm)
Initial	1.125	1	3.0	1.125*3*30 = 101.25
Development	1.3	1	3.2	1.3*3.2*30 =124.8
Mid-season	1.2	2	4.5	1.2*4.5*30 = 162
Late season	1.0	1	4.8	1.0*4.8*30 =144
At harvest	1.0	0.2	4.0	1.0*4.0*30 =120

4.0 CONCLUSION:

This study underscores the critical importance of localized water requirement assessment for rice cultivation in Central Cross River State, Nigeria, utilizing the Penman's equation to estimate reference evapotranspiration (ETo). The comprehensive climatic analysis over 42 years highlights significant seasonal and annual variations in rainfall, temperature, humidity, and wind speed, which directly influence crop water needs. The application of the Penman-Monteith model, coupled with crop-specific coefficients, provided reliable estimates of crop evapotranspiration (ETc) across different growth stages, facilitating precise water management strategies.

The findings reveal that effective water demand for rice in the region is highly seasonal, with peak requirements aligning with the major rainy months, thereby emphasizing the need for strategic irrigation planning during dry periods. The calculated effective rainfall and water requirements can serve as vital inputs for developing sustainable irrigation schedules, optimizing water use, and enhancing rice productivity under prevailing climatic conditions. Furthermore, this research demonstrates the applicability and robustness of Penman's equation as a practical tool for regional water resource management, especially in regions where climatic variability poses significant challenges.

This region-specific assessment provides valuable insights for policymakers, farmers, and water resource managers striving to balance rice production demands with sustainable water use. Future efforts should focus on integrating these findings into comprehensive water management frameworks and exploring climate change impacts to ensure resilient and sustainable rice cultivation in Central Cross River State.

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