

Assessment of Rice Crop Water Requirements under Changing Climatic Conditions in Makurdi, Nigeria (1980-2024)

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ABSTRACT

This study assessed the effects of climate change on rice water requirements in Makurdi, Nigeria. Reference evapotranspiration (ET_o) and rice crop water requirements were estimated using the CROPWAT 8.0 model over a 45-year period (1980–2024). Climatic data, including temperature, rainfall, relative humidity, solar radiation, and wind speed, were obtained from the Nigeria Meteorological Agency (NMets) and subjected to trend and statistical analyses. The Mann–Kendall trend test and Sen’s slope estimator revealed significant increasing trends in maximum temperature, mean temperature, annual rainfall, solar radiation, and wind speed, alongside declining trends in relative humidity and minimum temperature. These climatic changes have contributed to a marked increase in both reference evapotranspiration and rice crop water requirements over the study period. Pearson Product Moment Correlation analysis indicated strong positive relationships between temperature, wind speed, evapotranspiration, and crop water requirements. Multiple regression analysis further demonstrated that maximum temperature, rainfall, solar radiation, and wind speed exert significant positive influences on evapotranspiration and crop water demand, whereas minimum temperature and relative humidity showed negative effects. The assessment of climatic water availability indicates a progressive decline in water availability in Makurdi, primarily driven by increasing evapotranspiration rates. The study underscores the growing challenges posed by climate variability on agricultural water demand and highlights the need for improved irrigation management strategies. It recommends targeted capacity-building initiatives by agricultural research institutions, including farmer training on decision-support tools such as CROPWAT, dissemination of timely climate information, and the development of drought-tolerant and early-maturing rice varieties. Overall, the findings provide a robust scientific basis for enhancing climate resilience and optimizing water resource management in rice production systems in the study area.

Keywords: Reference Evapotranspiration, Rice, Crop Water Requirement, Climate Change, CROPWAT

INTRODUCTION

Climate change is considered as posing the greatest threat to agriculture and food security in the 21st century, especially in many poor, agriculture-based countries of Sub-Saharan Africa (SSA) with their low capacity to effectively cope (IPCC, 2015). (Kiprutto, Rotich and Riungu, 2015) opined that African agriculture is already under stress as a result of population increase, industrialization and urbanization, yet the impact of climate change is likely to exacerbate these stresses even further. Agricultural water consumption accounts for more than 70 percent of total water consumption worldwide and faces great competition with other water uses as the population grows and is directly related to food security (Jia, Zhang, Xie, Xue, Zhang and Han, 2022).

Water is one of the most vital input of agriculture and essential component required for growth and development of crops (Chandra and Kumari, 2021). Crop water requirements according to the United Nations Food and Agriculture Organization is the amount of water used by crops for growth (Majumdar, 2004). Crop water need represents the quantity of water needed or the quantity of water required to compensate the

evapotranspiration loss from the cropped field in order to grow optimally (Allen, Perreira, Raes and Smith, 2008). According to the report, evapotranspiration is a combined process of evaporation and transpiration from a vegetated surface through which water is lost from the soil surface and from crops. Climate is an important determining factor of crop water requirements (Allen et al, 2008) and as result, climate change has many implications for agricultural water demand. Since agriculture is the largest water using sector in the world (Raes, Steduto, Hsiao and Fereres, {2009), changes in agricultural water use due to climate change are likely to have large impacts on global water demand (FAO, 2017). Climate plays an important role in crop production and crop growth periods and crop water requirements are dependent on weather conditions (Iizumi and Ramankutty, 2015). According to Jiménez et al (2014), evapotranspiration is an important part of water balance and a key variable in the hydrologic cycle process. Based on global and regional climate models as well as physical principles, potential evapotranspiration over most land areas are very likely to increase in a warmer climate, thereby accelerating the hydrologic cycle (IPCC, 2013). According to Turrall (2011) cited by FAO (2017), climate change has impacted not only on hydrological cycle but also on the available water resources and agricultural water demand, there are concerns about the impacts of climate change on agricultural water demand and productivity. The IPCC (2007) stated that since the beginning of the 20th century, scientists have been observing a change in the climate that cannot be attributed to any of the “natural” influences of the past. Climate change and variability would be the principal source of fluctuation in global food production, particularly in the semi-arid tropical countries of the developing world. (Cisneros et. al., 2014) posits that crop water availability shortage and excess affects the growth and development of the plants, yields and quality of produces. Organization for Economic Co-operation and Development OECD, (2014) stated that climate change affects the water availability and water resources, which in turn affects agriculture.

Rice is the most important cereal for human consumption, meeting the needs of 50 percent of the world’s population (WMO, 2009). According to West African Rice Development Association (WARDA) 2008, rice is a daily staple food cultivated and consumed in Nigeria with a potential land area of between 4.6 million and 4.9 million hectares. The paper opined that the environmental constraints for rice production include poor drainage, insufficient rainfall for rain-fed lowland rice and drought. WARDA (2008) opined that varieties used and cultural practices adopted in rice cultivation vary widely and are influenced by local climatological elements (rainfall, temperature and solar radiation regimes). According to Terdoo, Ndabula and Abaje (2020), there is a growing scientific evidences that both the observed and projected changes in climate and its variability will adversely impact all sectors of the Nigerian economy (Abiodun, Lawal, Salami, and Abatan, 2013; Matthew, Abiodun, & Salami, 2015; Bosello, Campagnolo, Cervigni, and Eboli, 2017) including health, transportation, education and others, but studies have singled out agriculture as one of the sectors expected to bear most of the negative impacts of climate change and variability (CCV), given its dependence on weather and climatic conditions (FAO, 2017). Terdoo, Ndabula and Abaje (2020), stated that within the agricultural sector of Nigeria, rice production sub-sector is expected to bear most of the impacts of climate change and climate variability given its relative high exposure and sensitivity to CCV-related pressures (example, heat stress, drought), due to its reliance on natural weather processes (rainfall, temperature and sunshine). Thus, scientific reports have revealed this may impact rice production processes, through rising temperatures, decreasing rainfall, and changes in CO₂ concentrations, atmospheric humidity, and solar radiation (Ajetomobi, Abiodun& Hassan, 2010; Nwalieji & Uzuegbunam, 2012; Terdoo and Feola, 2016). Consequently, this will lead to crop failure and inability to provide food security, income and employment for million households across Nigeria.

According to the IPCC (2007), water demand by evapotranspiration and supply by rainfall to crops is projected to be modified as a result of climate change to the detriment of crop yield. As a consequence, more water will be withdrawn from the soil to the atmosphere and less water available for crop plants. The effect of differences in rainfall on the availability of moisture in tropical agriculture is especially great because of the rapid evaporation and transpiration by plants. Several studies reported an increasing trend of future irrigation water demand with substantial variations depending on the geographic location, the degree of global warming and associated changes in regional precipitation (Wada et al., 2013; Wang et al., 2016, 2017). Therefore, the regional scale assessment of changes in water requirement is very important. Using a combination of crop and geographic information systems, Diaz et al. (2007) predicted an increase in aridity and irrigation need in Spain. Climate change is expected to increase seasonal evapotranspiration and irrigation water requirement.

(Acharjee, Ludwig, van Halsema, Hellegers, and Supit, 2017) stated that most studies reported a decline in rice yield due to high temperature stress which reduces grain yield of rice by reducing the percentage of ripened grains as a result of spikelet sterility (Oh-e et al., 2007). The duration of the rice growing season and the time of flowering are also influenced by temperature, as higher temperatures usually result into a shorter rice growing season and to earlier flowering, which consequently affect the crop production and seasonal water use (Nonhebel, 1996; Wheeler et al., 2000). A shortening of growing season and an early flowering of various crops due to accelerated crop development as a result of higher temperatures has been reported for several regions (Estrella et al., 2007; Guereña et al., 2001; Supit et al., 2010; Williams and Abberton, 2004). The shortening of growth duration of a crop not only affects yield, but also the water requirements of crop (Acharjee, Ludwig, van Halsema, Hellegers, and Supit, 2017).

Therefore, this study assesses the effects of climate change on rice water requirements. A combination of increased water demand by crops and reduced rainfall have contributed to reduced yield. It is anticipated that the increasing demand for water by crops will affect water availability. Since agriculture in Nigeria is rain-fed, the country has been facing a growing threat from climate change leading to insufficient water availability and drought in northern Nigeria and an excess water availability in southern Nigeria, leading to flooding (Tajudeen et al; 2022). Recent studies show that droughts and low water availability have become constant in northern Nigeria and are expected to continue (Ladan, 2014), arising from a decline in precipitation, declining length of growing season and a rise in temperature (Aredhor, 2016; Tajudeen, et al., 2022). Increasing evapotranspiration demand has been predicted to increase crop water requirement by up to 15 percent in Nigeria by 2080 (Fischer, Tubiello, van Velthuizen, and Wiberg, 2007). Although Benue state is blessed with arable land and adequate rainfall, the amount, timing and patterns have declined due to climate change (Aredhor, 2016). Due to climate change leading to increasing temperature, crops face a high-water demand in order to meet the evaporative demand of the atmosphere to grow optimally. This has provided major concerns for rice farmers. It is anticipated that the declining water availability will adversely affect crops like wheat, maize and rice (IPCC, 2007). Increasing temperature and evapotranspiration resulting from climate change are expected to exacerbate water scarcity and water stress during the growing season leading to drought, crop failure and low yield with implication for food security. A combination of rising temperature and declining rainfall is exacerbating the evaporative water use of crops (IPCC, 2007), McCabe and Wolock (2007) and the quantity of water required by rice is increasing while the supply of water through rainfall is inadequate to meet with crop water requirements. Global and regional climate models as well as physical principles shows that potential evapotranspiration over most land areas is very likely to increase in a warmer climate due to increasing temperature, thereby accelerating the hydrologic cycle (Bates, Kundzewicz, Wu and Palutikof, 2008; IPCC, 2013), accompanied by decrease in soil moisture (Cisneros et al, 2014). The projections show that crop water requirements will increase in many regions due to climate change, especially in arid and semi-arid regions of the world with higher temperatures and increased variability of rainfall in both rain-fed and irrigated systems (FAO, 2017). Addressing these changes require information about changes in crop water requirement. Understanding possible changes in water requirement of rice is essential to cope with the changing water availability due to increased water demand.

Accurate determination of crop water requirements of rice is not available in Benue State. Most studies have concentrated on yield and economic impacts of climate change while others have attempted to estimate crop water requirements from field methods and or empirical methods for only a farming season. From review of available literatures, very little work is available on the use of the CROPWAT program to determine crop water requirements of rice for forty-five (45) years and to evaluate the impacts of increasing temperature and changing rainfall patterns on crop water requirements of rice in Makurdi, Benue State.

MATERIALS AND METHODS

Study Area

Makurdi is the capital city of Benue state and lies between latitude 07°41' N and 07°53' N and longitude 08°24'E and 08°38'E (Figure 1). The area is made up of extensive area of gently undulating land that lies within 50 –100m above the sea level on the bank of the Benue River. Makurdi town lies entirely in the Benue

plain, which makes the relief generally low- laying. However, several interfluvies at the High Level, Mission Ward, Old GRA areas where the elevation is above 97 meters. The area lies within the tropical continental climate with distinguished wet and dry seasons. The wet season lasts for seven months from April to October while the dry season lasts for five months from November to March. The two seasons are controlled by the two prevailing air masses in Nigeria: the tropical continental air mass blows from the Sahara Desert and brings dry season to the area. The tropical maritime air mass blows from the Atlantic Ocean and results in rainfall to the area. The area experiences high temperature of about 26-35⁰c. The mean annual rainfall is about 1500-2500mm while the mean monthly rainfall is about 50mm. The rainy season's mean duration is 182 days, with the highest monthly rainfall total of 221mm is recorded in August. Seasonal atmospheric humidifies are 80percent for the wet and 30 percent for dry seasons. Wind speed is generally light to moderate except the squall lines that often gust at 66km/h. The people of the area are mainly engaged in farming, fishing and commerce.

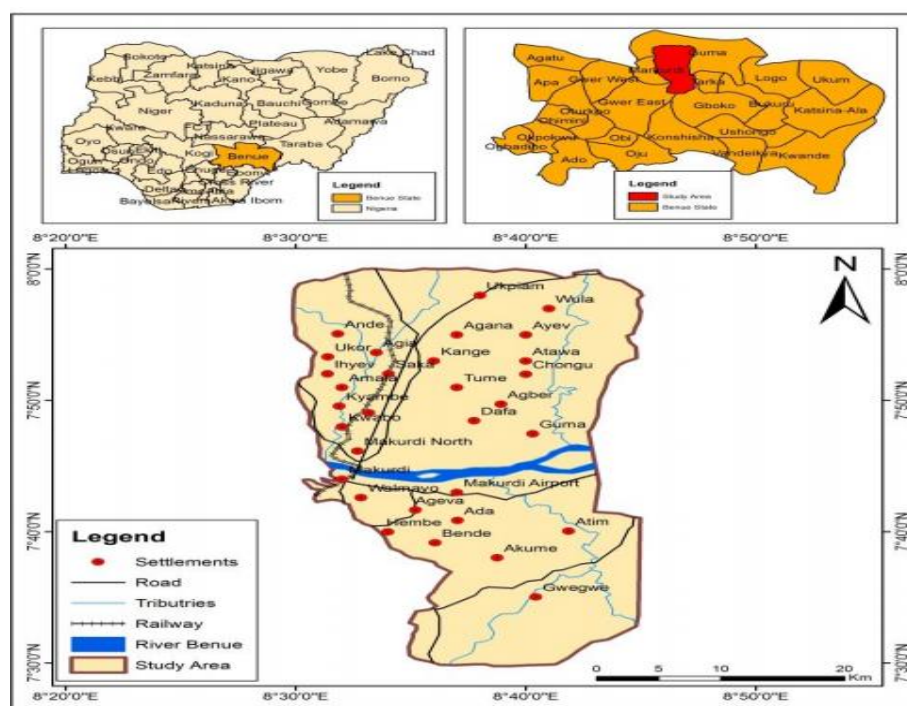


Figure 1: Administrative Map of Benue State showing Makurdi (Source: Oyatayo, Ndabula, Abaje, Jidauna, Iwan, Mshelia, 2020).

Data Needs

This study requires quantitative to assess the effects of climate change on rice water requirements in Makurdi, Benue State. The data required include climatic data including monthly minimum and maximum temperatures (⁰C), relative humidity (%), wind speed (Km/day), solar radiation (hours) and rainfall (mm); crop data and soil data.

Methods of Data Collection

The data required for this analysis were collected from secondary sources. The climatic data were collected from the Nigerian Meteorological Agency (NiMet) Abuja while the crop data and soil data were collected from the archives and records of the Food and Agriculture Organization (FAO) and the Federal University of Agriculture, Teaching and Research Farm Makurdi and Copernicus Data Store.

Methods of Data Analysis

The Food and Agriculture Organization (FAO) Penman-Monteith method in the CROPWAT 8.0 software on WINDOWS was used to estimate the reference crop evapotranspiration and crop water requirements of rice in

the area. The reference evapotranspiration was estimated in the CROPWAT software using the Penman-Monteith method given as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \left(\frac{900}{T + 273} \right) U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \dots\dots\dots (1)$$

Where γ = Psychometric constant (KPa/0C)

Δ = Slope of Vapour pressure curve (KPa/0C)

R_n = Net Radiation (MJ/m²/day)

G =Ground (Soil) heat flux density (MJ/m²/day).

T = Mean daily temperature at 2m height.

U_2 = Wind speed at 2m height

e_s = saturation vapour pressure.

e_a = actual vapour pressure.

The rice crop water requirement is estimated through the coefficient integrated model approach as follows:

$$ET_c = K_c * ET_o \dots\dots\dots (2)$$

Where ET_o is reference evapotranspiration rate,

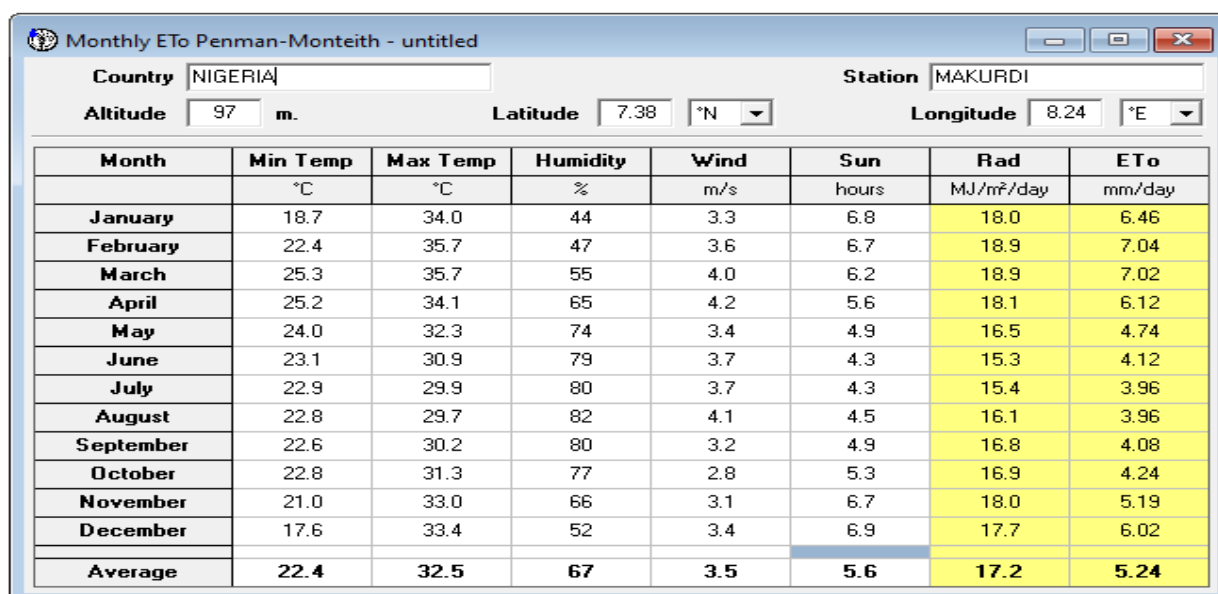
K_c is crop coefficient,

ET_c is crop evapotranspiration.

RESULTS AND DISCUSSIONS

Estimation of Reference Evapotranspiration from Climatological data

Reference evapotranspiration (ET_o) for each year from 1980 to 2024 was calculated using FAO CROPWAT 8.0 model from mean climatological data. The sample result is presented in Figure 2



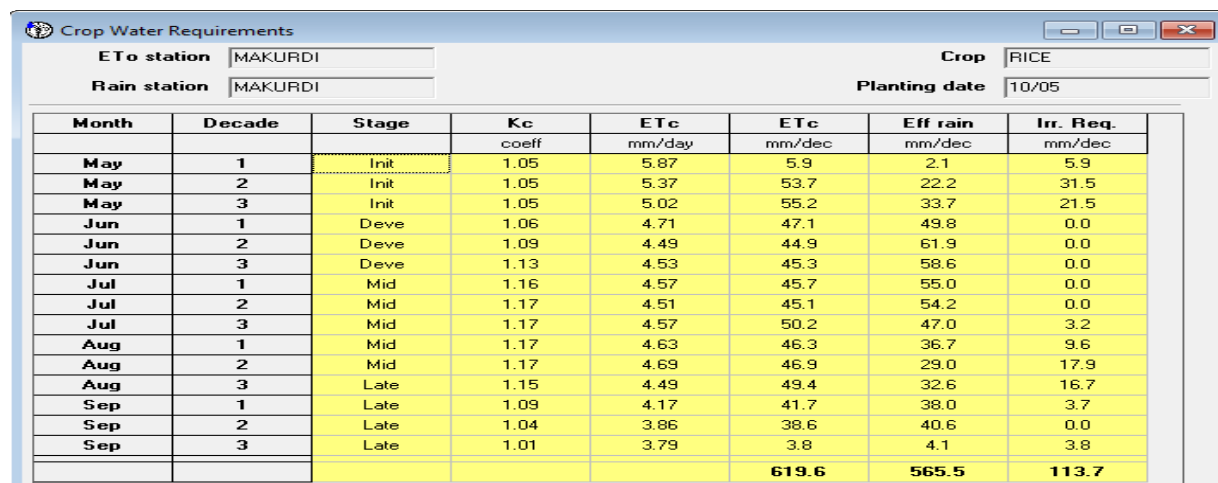
Month	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun hours	Rad MJ/m²/day	ETo mm/day
January	18.7	34.0	44	3.3	6.8	18.0	6.46
February	22.4	35.7	47	3.6	6.7	18.9	7.04
March	25.3	35.7	55	4.0	6.2	18.9	7.02
April	25.2	34.1	65	4.2	5.6	18.1	6.12
May	24.0	32.3	74	3.4	4.9	16.5	4.74
June	23.1	30.9	79	3.7	4.3	15.3	4.12
July	22.9	29.9	80	3.7	4.3	15.4	3.96
August	22.8	29.7	82	4.1	4.5	16.1	3.96
September	22.6	30.2	80	3.2	4.9	16.8	4.08
October	22.8	31.3	77	2.8	5.3	16.9	4.24
November	21.0	33.0	66	3.1	6.7	18.0	5.19
December	17.6	33.4	52	3.4	6.9	17.7	6.02
Average	22.4	32.5	67	3.5	5.6	17.2	5.24

Figure 2: Output window for monthly Reference Evapotranspiration on CROPWAT in Makurdi

(Source: Researcher's calculation on CROPWAT 8.0, 2024)

Estimation of Crop Water Requirement of Rice

To estimate the actual rice crop water requirement, the reference evapotranspiration is multiplied with the crop coefficient during the growing stages and summed at the end of the growing season. The result is shown in Figure 3.



Month	Decade	Stage	Kc	Etc	Etc	Etc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec	mm/dec
May	1	Init	1.05	5.87	5.9	2.1	5.9	
May	2	Init	1.05	5.37	53.7	22.2	31.5	
May	3	Init	1.05	5.02	55.2	33.7	21.5	
Jun	1	Deve	1.06	4.71	47.1	49.8	0.0	
Jun	2	Deve	1.09	4.49	44.9	61.9	0.0	
Jun	3	Deve	1.13	4.53	45.3	58.6	0.0	
Jul	1	Mid	1.16	4.57	45.7	55.0	0.0	
Jul	2	Mid	1.17	4.51	45.1	54.2	0.0	
Jul	3	Mid	1.17	4.57	50.2	47.0	3.2	
Aug	1	Mid	1.17	4.63	46.3	36.7	9.6	
Aug	2	Mid	1.17	4.69	46.9	29.0	17.9	
Aug	3	Late	1.15	4.49	49.4	32.6	16.7	
Sep	1	Late	1.09	4.17	41.7	38.0	3.7	
Sep	2	Late	1.04	3.86	38.6	40.6	0.0	
Sep	3	Late	1.01	3.79	3.8	4.1	3.8	
					619.6	565.5	113.7	

Figure 3: Output window of Crop Water Requirement for Rice during in 2024 using CROPWAT model

(Source: Researcher's calculation using CROPWAT, 2024)

Changes in reference evapotranspiration and Rice Water Requirements in Makurdi

Changes in reference evapotranspiration and rice water requirements were analyzed by considering trend values of the climate variables using the Mann-Kendal trend analysis and Sen's slope estimator. The Mann-Kendall trend and Sens's slope estimator are widely used in hydrological and climatological analysis of time series (Dani and Pal, 2017). The non-parametric Mann-Kendall rank test identifies monotonic trends, over time, for given variables, and establishes whether the trend is upwards or downwards. Result is presented in Table 1

Table 1: Mann-Kendal trend of Reference Evapotranspiration and Rice Water Requirement in Makurdi from 1980-2024

Time series	First year	Last Year	N	Test S	Test Z	Signific.	Q
Total ETo	1980	2024	45		2.76	**	3.463
CWR	1980	2024	45		3.99	***	1.331

* *CWR= Crop Water Requirement and ETo =reference evapotranspiration*

(Source: Researcher's computation, 2024)

The result of the trend analysis of climatic variables in the area showed a statistically significant positive trend was found for reference evapotranspiration and crop water requirement. This implies that the changes in climate is having significant effect on crop water demand in the area.

Trend of Reference Evapotranspiration and Crop Water Requirement

The Mann-Kendall trend analysis indicate that reference evapotranspiration has increased. The value of Z of annual reference evapotranspiration is 2.76 (more than $Z_{0.025}$) where with $Z_{0.025} = 1.96$ at 5 percent, which

makes it statistically significant, indicating that the increase in reference evapotranspiration is significant with a Sen's slope of 3.463. This indicates that annual reference evapotranspiration has increased by 3.463 mm/year

and 34.63 mm per decade. The Mann-Kendall trend analysis indicates that and crop evapotranspiration of rice have increased during the growing season. The value of Z of 3.99 (more than $Z_{0.025} = 1.96$ at 5 percent, which makes it statistically significant, indicating that the increase in crop evapotranspiration is significant with a Sen's slope of 1.331. The increase in temperature with increase in evapotranspiration will exacerbate crop water requirement and increase water stress. Figure 4 and 5 show the trend of annual reference evapotranspiration and crop water requirement in the study area for the period of 45 years. From the figure, it can be seen that the total annual reference evapotranspiration in the study area for the time frame of study has been fluctuating and increasing.

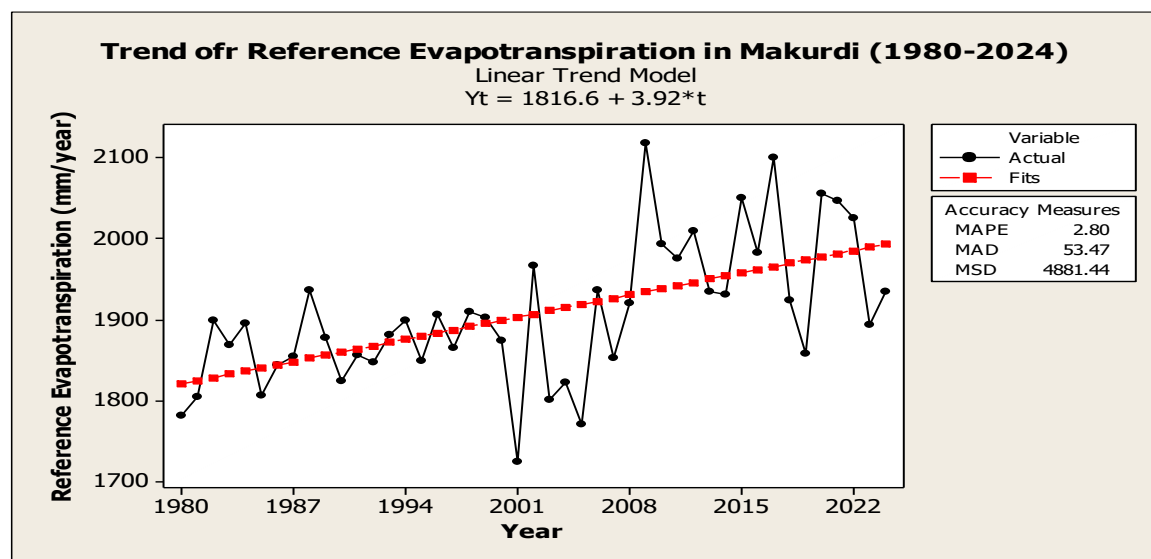


Figure 4.19. Trend analysis of annual reference evapotranspiration in Makurdi from 1980-2024.

Source: Researcher's calculation using Minitab

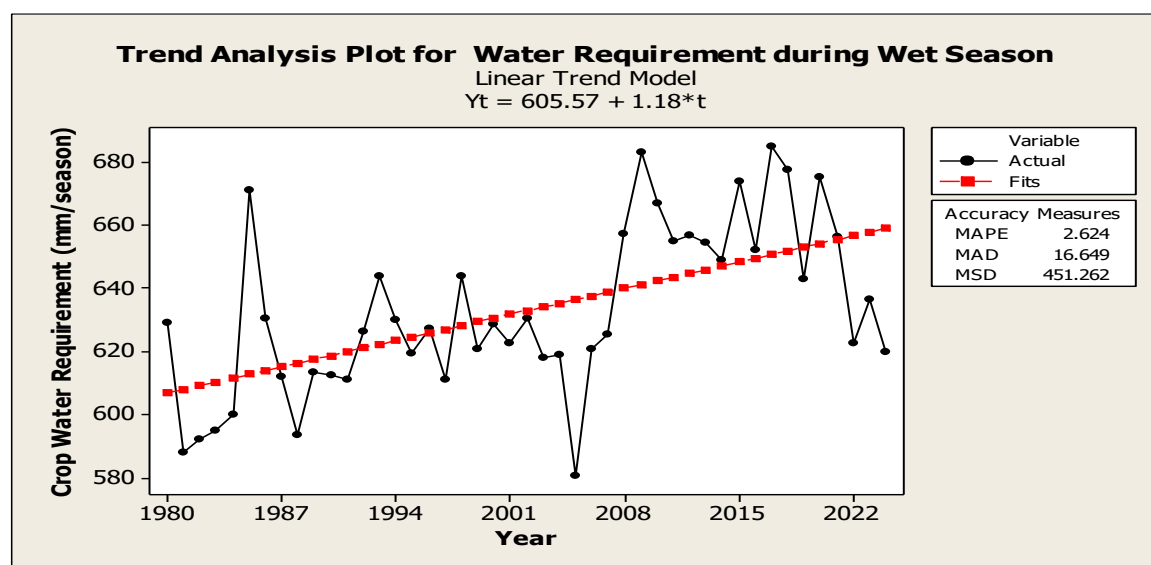


Figure 5: Trend analysis of Crop Water Requirement for Rice in Makurdi (1980-2024)

Source: Researcher's calculation using Minitab, 2024

From the trend analysis plot, rice crop water requirement in the study area exhibits a positive trend, and thus indicate an increase in crop water requirement and increase in crop water demand.

Implications of climate change on water requirement of rice in Makurdi

The multiple regression analysis was conducted to establish the influence of climatic variables on on reference evapotranspiration and crop water requirements. The result is presented in Table 3.

Table 3: Regression Analysis of ETo and climate variables

The regression equation is $ETo = 0.47 + 0.191 \text{ Max T} + 0.0533 \text{ Min T} + 0.00171 \text{ Rainfall} - 0.0685 \text{ RH} + 28.6 \text{ Rs} + 0.322 \text{ WS}$

Predictor	Coef	SE Coef	T	P
Constant	0.472	2.665	0.18	0.868
Max T	0.19099	0.06015	3.18	0.034
Min T	0.05329	0.03814	1.4	0.235
Rainfall	0.00171	0.00064	2.66	0.057
RH	-0.0685	0.01235	-5.54	0.005
Rs	28.56	15.18	1.88	0.133
WS	0.32154	0.05289	6.08	0.004
S	0.04741			
R-Sq	99.90%			
R-Sq(adj)	99.80%			

Source: Researcher's computation, 2024

Table 3 shows the result of the effects of climate change on reference evapotranspiration at 0.05 significance level (α). The result shows a positive slope (0.47) with positive constant for maximum temperature, rainfall, solar radiation and wind speed. This implies that maximum temperature, rainfall, solar radiation and wind speed contributed positively to reference evapotranspiration while minimum temperature and humidity have a negative relationship. From the table, maximum temperature, humidity and wind speed contributed to reference evapotranspiration variation in the area with an R^2 of 99.8 percent. This indicates that the model predicts 99.8 % variation in reference evapotranspiration. The result also indicates that wind speed and relative humidity have the greatest contribution with variation in reference evapotranspiration followed by solar radiation and maximum temperature. Relative humidity and minimum temperature have negative contribution to reference evapotranspiration variation in Makurdi. A one-way ANOVA was used to determine the significance of the regression analysis. If p the associated probability (0.000) is less than 0.05, the null hypothesis (H_0) will be rejected. To test the significance of the regression model, analysis of variance was conducted. The ANOVA table is presented in Table 4.

Table 4: Summary of one-way ANOVA for effects of climate variables on reference evapotranspiration

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	7	15.5845	2.2264	990.47	0
Residual Error	4	0.009	0.0022	—	—
Total	11	15.594	—	—	—

Source: Researcher's computation, 2024

The ANOVA table in Table 4 shows that the regression model is significant and can predict the effects of climatic variables on reference evapotranspiration. The p-value is $0.000 < 0.05$ which shows that the model is significant.

The regression of climatic variables and crop water requirement of rice is presented in Table 5 and shows the result of the effects of climate change on crop water requirement at 0.05 level of significance.

Table 5: Regression Analysis of Crop Water Requirement and Climate Variables

The regression equation is $CWR = 787 + 12.4 \text{ MAX T} - 16.7 \text{ MIN T} - 0.044 \text{ MEAN R} - 3.13 \text{ Mean RH} - 3.24 \text{ Mean Rs} + 26.8 \text{ Mean WS}$

Predictor	Coef	SE Coef	T	P
Constant	786.9	362.9	2.17	0.036
MAX T	12.408	5.058	2.45	0.019
MIN T	-16.731	7.015	-2.39	0.022
MEAN R	-0.0438	0.1889	-0.23	0.818
Mean RH	-3.132	1.259	-2.49	0.017
Mean Rs	-3.237	7.282	-0.44	0.659
Mean WS	26.825	7.828	3.43	0.001
S	20.4062			
R-Sq	48.80%			
R-Sq (adj)	40.70%			

Source: Researcher's computation, 2024

The result shows a positive slope (787mm) with negative constant for minimum temperature and relative humidity while maximum temperature, solar radiation and wind speed showed positive constant with an R^2 of about 40.7 percent. There is a significant positive influence of maximum temperature ($a=12.408$, $p=0.019<0.05$) and wind speed ($a=26.285$, $p=0.001<0.05$) while minimum temperature and relative humidity have significant negative effects on crop water requirement of rice in Makurdi ($a= - 16.731$, $p=0.022 <0.05$) and ($a= - 3.132$, $p=0.017<0.05$). There is an insignificant positive effect of rainfall ($a=0.283$, $p=0.818>0.05$), mean solar radiation ($a=-3.237$, $p=0.656>0.05$) on crop water requirement of rice in Makurdi.

This implies that maximum temperature and wind speed contributed positively to crop water requirement while relative humidity and minimum temperature have a negative contribution towards crop water requirement of rice. To test the significance of the regression model, the ANOVA was used. The ANOVA table is presented in Table 6. The p-value shows that the model is significant ($p=0.000$) for predicting the effects of climate change on crop water requirement in Makurdi.

Table 6: Summary of one-way ANOVA for effects of climate variables on CWR

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	15090.3	2515.1	6.04	0
Residual Error	38	15823.7	416.4	—	—
Total	44	30914	—	—	—

Source: Researcher's computation, 2024

CONCLUSION

The study was aimed at assessing the effects of climate change on rice water requirements. Reference evapotranspiration and rice crop water requirement in Makurdi were determined using the CROPWAT 8.0

model of the Food and Agriculture Organization from 1980 to 2024. The result of the Mann-Kendal trend analysis indicated that reference evapotranspiration and crop water requirements have increased in Makurdi over the study period due climate change. Changes in temperature led to increase in reference evapotranspiration and atmospheric water demand that increased crop water requirement of rice. The result showed that increase in temperature, wind speed and annual rainfall data and a decline in relative humidity led to increases in atmospheric water demand that contributes to increase in reference evapotranspiration and rice water requirement from 1980-2024. This implies that the changes in climate is having significant impact in crop water demand in the area. To determine the effects of climatic variables on reference evapotranspiration and crop water requirements, the effects of climatic variables on reference evapotranspiration and crop water requirements were tested on a month-to-month basis using multiple regression analysis. The result a positive slope with positive constant for maximum temperature, rainfall, solar radiation and wind speed. This implies that maximum temperature, rainfall, solar radiation and wind speed contributed positively to reference evapotranspiration while minimum temperature and humidity negatively influenced reference evapotranspiration. Maximum temperature, humidity and wind speed contributed to evapotranspiration variation in the area with an R^2 of 99.8 percent. The result shows continuous increase in reference evapotranspiration and rice water requirements. From the study, there is clear evidence that climate has changed in monthly and annual reference evapotranspiration and crop water requirement increased in recent years. The result showed an increasing trend of water demand by crops. The crop water requirement of wet season rice and dry season rice presented a significant increasing trend from 1980 to 2024 in Makurdi, Benue State and this finding was relatively consistent with the results of previous studies. The study is consistent with (Ilesanmi, Oguntunde and Olubango, 2023; Reta, Hatiye, and Finsa. (2024).). Forecast shows that water demand by crops will continue to increase in the future due to climate change while available water continues to decline. This calls for concern to mitigate adverse effects. The rainfall alone could not meet the ETo demand of crop during the dry season. The remaining water needs to be applied externally through irrigation. A good irrigation practice applies right quantity of water at the right time. However, the overall decreasing trend of the irrigation water requirement is due to the increasing trend of rainfall. Rice farmers showed high level of awareness of climate change and have responded to the challenge by developing adaptation measures to cope with the effects. Farmers are aware of the effects and try a lot of measures to adapt. However, the use of CROPWAT for irrigation scheduling is still low in the area. A lot needs to be done.

RECOMMENDATIONS

Climate change is a threat to crop production in the area. The study concluded that crop water requirements of rice will continue to increase due to climate change as the years go by. A number of actions have been taken to cope with the adverse effects of climate change in the area to protect livelihood. However, a lot needs to be done to cushion the effects of climate change on crop water requirements and rice production in the area. These include adoption of irrigation scheduling with CROPWAT and other soil moisture water resources models at farm levels, shifting to drought resistant rice cultivars, water harvesting, optimizing planting dates, enhancement of irrigation efficiency through scheduling to reduce water misuse, adopting climate smart agriculture, training farmers on efficient water management, adopt crop diversification, early climate warning system, training of extension services agents, adequate and regular information on current issues of climate change on agriculture through mass media and the adoption of early maturing, drought and flood resistant varieties of rice to cope with the vagaries of climate change.

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