Modelling the Relationships among Climate Variables, Reference Evapotranspiration and Rice Crop Water Requirement in Makurdi, Nigeria

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ABSTRACT

This study assesses the relationships among climate variables, reference evapotranspiration and rice water requirement in Makurdi, Nigeria Reference evapotranspiration (ETo) and rice crop water requirements were estimated using the CROPWAT 8.0 model over a 45-year period (1980–2024). The Mann–Kendall trend test and Sen's slope estimator was used to detect monotonic increase or decrease in water demand. The result revealed significant increasing trends in both reference evapotranspiration and rice crop water requirements over the study period. Correlation analysis was used to determine the relationship between climatic variables, reference evapotranspiration and crop water requirement of rice. The result indicated strong positive relationships between temperature, wind speed, reference evapotranspiration, and crop water requirements. 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 Waer Requirement, Climate Change, CROPWAT

INTRODUCTION

CROPWAT for windows is a computer program developed by the Food and Agriculture Organization of the United Nations for the calculations of crop water requirements and irrigation water requirements using climatic, crop and soil data (Abdulla, Bilena and Aadmir, 2015; Manasa and Shivapur, 2016). The model carries out calculations for reference evapotranspiration, crop water requirements and irrigation requirements in order to develop irrigation schedules under various management conditions. The most common version CROPWAT 8.0 was developed by the Land and Water Development Division of the Food and Agriculture Organization of the United Nations, in Italy and National Water Research Center, Egypt (Food and Agriculture Organization, 2009; Verma and Singh, 2019). CROPWAT 8.0 software estimates the crop water requirements of crops during the growing season and utilizing irrigation where insufficient water is available to meet water loss for optimum development and growth of crops (Aydın, 2022). The FAO-CROPWAT model has been successfully used in many parts of the world for different crop patterns under irrigated as well as rain-fed conditions (Alhassan et al., 2015). Many studies have been conducted to determine the crop water requirement (CWR) for different plants in different climate and soil conditions. (Incoom, Adjei, Odai, Akpoti and Siabi (2022), Maingi, Ndiiri and Mati (2020), Akinbile (2010), Adeniran et al, (2010), Abraham and Muluneh, (2022), Aydın (2022). The CROPWAT 8.0 software has been widely used in different geographical regions and climatic conditions to calculate crop water requirements (ETc) and irrigation water requirements (IWR) of field crops (Verma and Singh, 2019; Aydin, 2022). Studies have shown that climate change has a considerable impact on global water cycles, as well as on agriculture, and the sustainable use of agricultural water resources is facing continuing challenges, especially in regions with unbalanced water supply and demand (Jia et al, 2022). 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).

Climate is an important determining factor of crop water requirements (Allen et al, 2008). Therefore, climate change could have 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). 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).

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. 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). Consequently, this will lead to crop failure and inability to provide food security, income and employment for million households across Nigeria.

The use of CROPWAT for irrigation scheduling for efficient supply of water and to avoiding both water stress and water wastage is limited in Makurdi, despite climate change. 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). 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). Therefore, this study assesses the relationship among climate variables and effects on reference evapotranspiration and rice water requirements in Makurdi.

MATERIALS AND METHODS

Study Area

This research work was conducted in Makurdi, Benue State, Nigeria. Makurdi is the capital city of Benue state and lies on the River Benue's flood plains between latitude $07^0$41' N and $07^0$53' N and longitude $08^0$24'E and $08^0$38'E. The area has a population of 1,356,225 with 683,157 males and 673,068 females (National Population Commission, Census, 2006) and a population density of 17 persons per square kilometer. The Federal University

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of Agriculture, Lower Benue Irrigation Project and the Benue State University are the major tertiary institutions that are located in Makurdi.

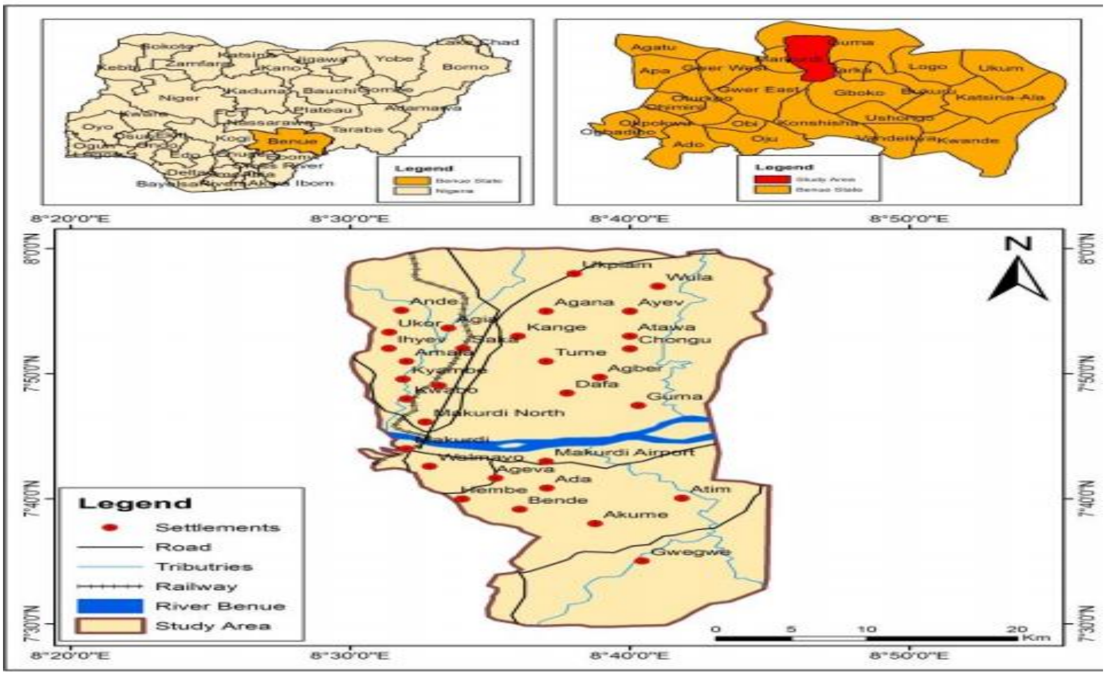

Figure 1: Administrative Map of Benue State showing Makurdi (Source: Oyatayo, Ndabula, Abaje, Jidauna, Iwan, Mshelia, 2020)**.**

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 with mean 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 26-35^{0}c. 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. Crops cultivated are vegetables and cereals. Other economic activities include market gardening and fishing at the river Benue.

Data Needs

This study requires quantitative data to assess relationships among climate variables, reference evapotranspiration and rice crop water requirement in Makurdi, Nigeria. The climatological data include monthly minimum and maximum temperatures (^{0}C), 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 Nigeria Meteorological Agency (NiMets) 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.

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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 within the two growing seasons from 1980-2024. Both descriptive and inferential statistics were used to analyze the data.

Estimation of Crop Water Requirement of Rice

Crop water requirement of rice was estimated through a crop coefficient model integrated approach as follows:

$$ETc = Kc * ETo \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

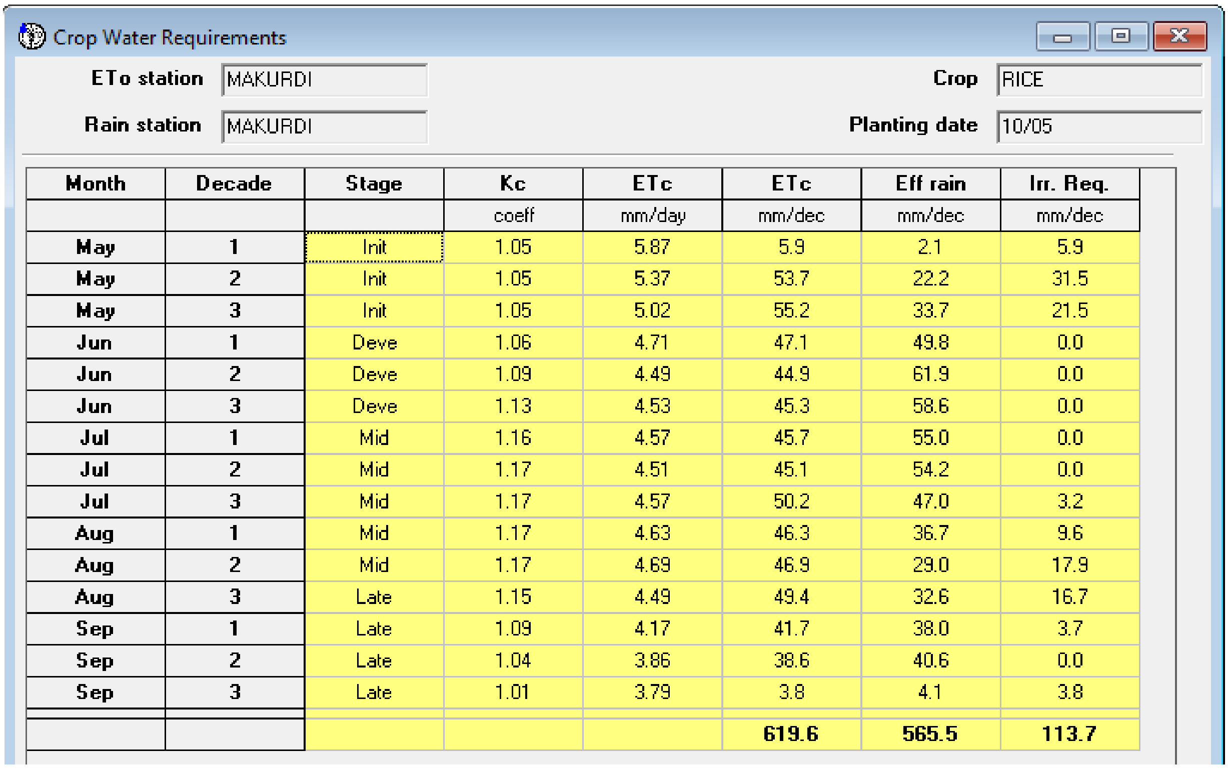
Where ETo is reference evapotranspiration rate,

Kc is crop coefficient,

ETc is crop evapotranspiration.

RESULTS AND DISCUSSION

Estimation of reference evapotranspiration and crop water requirement of rice.



Crop Water Requirements

ETo station: MAKURDI — Crop: RICE

Rain station: MAKURDI — Planting date: 10/05

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	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 2: Output window of Crop Water Requirement for Rice in 2024 using CROPWAT model

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

Changes in Crop Water Requirements of rice due to Climatic Change in Makurdi Changes in crop water requirements of rice due to climate change was analyzed using trend analysis. The crop water requirement of rice estimated from the CROPWAT model was analyzed in order to show the pattern of change for the time frame of study. The result of the Mann-Kendall trend test of during the growing seasons in Makurdi is presented in Table 1

Table 1: Mann-Kendal trend analysis of climate variables in Makurdi from 1980-2024

Time series	First year	Last Year	N	Test S	Test Z	Signific.	Q
Mean T	1980	2024	45		3.14	**	0.017
Total ETo	1980	2024	45		2.76	**	3.463
CWR	1980	2024	45		3.99	***	1.331

***** *Mean T=mean temperature, CWR= Crop Water Requirement and ETo =reference evapotranspiration***

(Source: Researcher's computation, 2024)

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 $Z_{0.025}$) where $Z_{0.025} = 1.96$ 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. This indicates that crop evapotranspiration has increased by 1.331 mm/year and 13.31 mm per decade. The increase in temperature with increase in evapotranspiration will exacerbate crop water requirement and increase water stress. Figure 3 show the trend of 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. This indicates that the changes in crop water requirements of rice is significant and affecting water demand in the area.

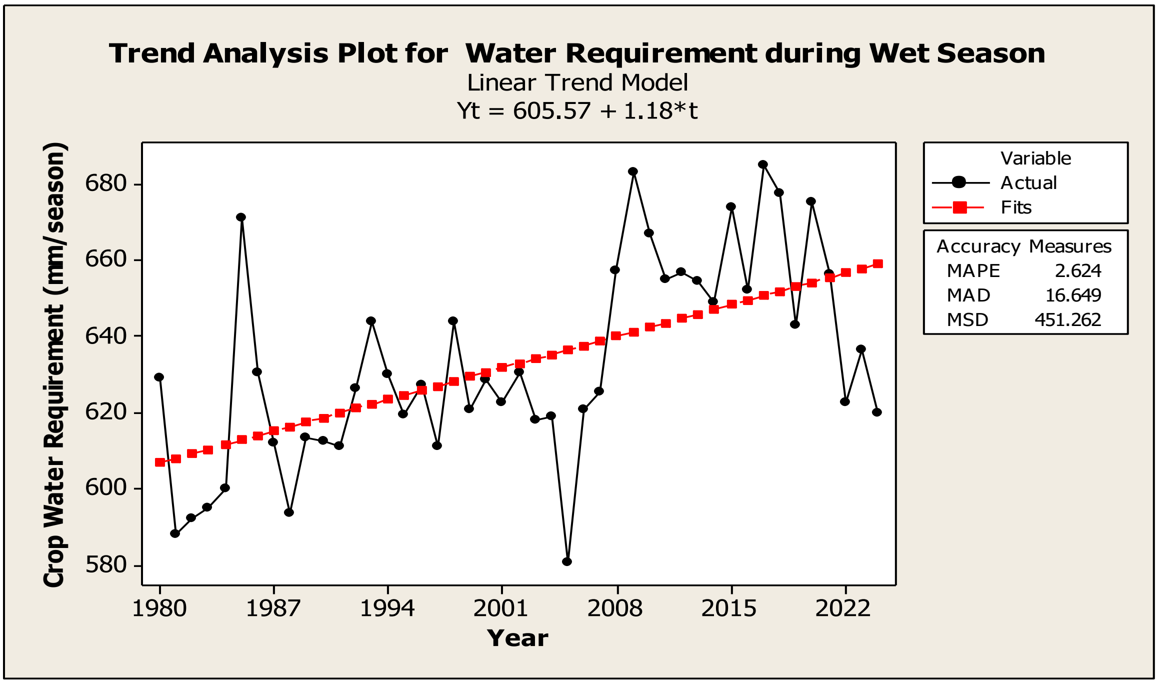


Figure 3: Trend analysis of Crop Water Requirement for Rice in Makurdi (1980-2024)

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.

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Relationship between climate variables, reference evapotranspiration and rice water requirements in the study area from 1980-2024.

The potential causes of the significant trends in reference evapotranspiration and crop water requirements were investigated through a correlation and regression analysis. The result of the correlation analysis of annual climatic data and reference evapotranspiration is presented in Table 2.

Table 2: Correlations of annual climate variables and reference evapotranspiration

	MAX T	MIN T	MEAN R	Mean RH	Mean Rs	Mean WS	Mean T
MIN T	0.193						
	0.205						
MEAN R	0.255	-0.109					
	0.091	0.474					
Mean RH	0.090	0.272	-0.135				
	0.557	0.071	0.376				
Mean Rs	-0.428	-0.655	-0.050	-0.137			
	0.003	0.000	0.745	0.368			
Mean WS	0.266	0.174	0.123	0.307	0.037		
	0.077	0.254	0.421	0.040	0.807		
Mean T	0.811	0.730	0.112	0.225	-0.688	0.288	
	0.000	0.000	0.464	0.137	0.000	0.055	
CWR	0.370	-0.320	0.207	-0.239	0.253	0.405	0.104
	0.012	0.032	0.721	0.114	0.093	0.006	0.496
Sum Eto	0.462	-0.173	0.283	-0.527	0.067	0.475	0.218
	0.001	0.255	0.060	0.000	0.661	0.001	0.150

Cell Contents: Pearson correlation

P-Value

Source: Researcher's computation using Minitab, 2024.

The relationship between climatic variables and reference evapotranspiration was analyzed using Pearson Product Moment Correlation method. The hypothesis was tested at 5 percent significance level. From the Pearson's correlation shown in Table 4.13, there is a significant positive relationship between reference evapotranspiration and maximum temperature (r=0.462, p=0.001<0.05) and wind speed (r=0.475, p=0.001<0.05). Minimum temperature has an insignificant negative relationship with reference evapotranspiration (r= - 0.173, p=0.255 >0.05). There is an insignificant positive relationship between rainfall (r=0.283, p=0.060>0.05), mean temperature (r=0.218, p=0.150>0.05), solar radiation (r=0.067, p=0.661>0.05) and reference evapotranspiration. There is a significant negative relationship between reference evapotranspiration and relative humidity (r= -0. 527, p=0.000<0.050). The correlation between climate variables and crop water requirement was also analyzed. From the Pearson's correlation shown in Table 4.13, there is a significant positive relationship between rice water requirements and maximum temperature (r=0.370, p=0.012<0.05) and wind speed (r=0.405, p=0.006<0.05). Minimum temperature has a significant negative relationship with rice water requirements (r= - 0.320, p=0.032 <0.05) while there is an insignificant positive relationship between rainfall (r=0.207, p=0.721>0.05), mean temperature (r=0.104, p=0.496>0.05), solar radiation (r=0.252, p=0.093>0.05) and crop water requirement. There is an insignificant negative relationship between rice water requirements and relative humidity (r= -0.239, p=0.114>0.050). Thus, the increase in maximum temperature and wind speed with a decline in relative humidity contributed to the increase in reference evapotranspiration and water demand. According to the result, there is a significant positive linear relationship between climatic variables and evapotranspiration. This result therefore shows that, increase in maximum temperature and wind speed and a decline in relative humidity led to increases in atmospheric water demand which contributes to increase in rice water requirement. The rise in temperature and wind speed along with the rise crop water requirement and reference evapotranspiration will adversely affect soil moisture and increase water demand of crops in the area.

The relationship between climatic variables and crop water requirement was analyzed using Pearson Product Moment Correlation method. The hypothesis was tested at 5 percent significance level. The result is presented in Table 3.

Table 3: Correlations: Max T, Min T, Rainfall, RH, WS, SSH and CWR

	Max T	Min T	Rainfall	RH	WS	Rs
Min T	0.106	0.487				
Rainfall	0.270	-0.067				
	0.073	0.664				
RH	-0.323	0.237	0.019			
	0.030	0.117	0.902			
WS	0.153	-0.056	0.219	0.149		
	0.315	0.717	0.149	0.328		
Rs	-0.232	-0.618	-0.049	-0.023	0.049	
	0.125	0.000	0.751	0.883	0.748	
CWR	0.048	-0.321	-0.008	-0.383	0.458	0.332
	0.752	0.032	0.957	0.009	0.002	0.026

Cell Contents: Pearson correlation

P-Value

From the Pearson's correlation shown in Table 4.14, there is a significant positive relationship between solar radiation (r=0.332, p=0.026<0.05) and wind speed (r=0.458,p=0.002<0.05) with rice water requirements. Rainfall has insignificant negative relationship with crop water requirement with rainfall (r= -0.008, p=0.957>0.05) while relative humidity (r= -0.383, p=0.009<0.05) and minimum temperature (r= - 0.321, p=0.032 <0.05) show significant negative correlation with crop water requirement. There is a non-significant positive relationship between crop water requirement and maximum temperature (r=0.048, p=0.752>0.05). Thus, the decrease in minimum temperature with an increase in wind speed and sunshine duration contributed to the increase in water demand during the growing seasons. According to the result, there is a significant positive linear relationship between climatic variables and crop water requirement of rice).

DISCUSSION

The study assessed the relationships among climate variables, reference evapotranspiration and Rice water requirement in Makurdi, Nigeria**.** 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 data estimated from CROPWAT model were analyzed for trend. The Mann-Kendall trend indicate that reference evapotranspiration and rice crop water requirement of rice have increased. The study found that both reference evapotranspiration and crop water requirements have increased in Makurdi over the study period due to higher temperature that led to increase in reference evapotranspiration and atmospheric water demand that increased crop water requirement of rice. The potential causes of the significant trends in reference evapotranspiration and crop water requirements were investigated through a correlation with the climatic variables. The hypothesis was tested at 5 percent significance level. From the Pearson's correlation, there is a significant positive linear relationship between climatic variables, evapotranspiration, and crop water requirement. This result therefore shows that, increase in maximum temperature and wind speed and a decline in relative humidity led to increases in atmospheric water demand which contributes to increase in rice water requirement. The rise in temperature and wind speed along with the rise crop water requirement and reference evapotranspiration will adversely affect soil moisture and increase water demand of crops in the area.

CONCLUSION

Climate change is a threat to agriculture and rice production. From the study, there is clear evidence that climate has changed in the area with reference evapotranspiration and crop water requirement increasing in recent years. The crop water requirement of 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 Olubanjo, 2023; Reta, Hatiye, and Finsa. (2024).**).** The increasing temperature and wind speed lead to increase in reference evapotranspiration and atmospheric water demand which increased crop water requirement and increase water stress on crop. 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 water demand of crop especially 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. Increasing crop water requirement demands increased irrigation.

RECOMMENDATIONS

Climate change is a threat to crop production in the area. 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.

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