

# RELATIONSHIP BETWEEN CLIMATIC VARIABILITY AND WATER FOOTPRINT OF SUGARCANE AT DANGOTE SUGAR COMPANY NUMAN, NIGERIA

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## ABSTRACT

This study investigated the relationship between climatic variability and water footprint of sugarcane at Dangote Sugar Company (formerly Savannah Sugar Company) Numan, Nigeria. The objective of the study was to assess the level of the effect of climatic elements- rainfall, temperature, relative humidity, sunshine and wind speed, on sugarcane production. Three sets of data were required for the study, including climatic, soil and crop parameters. Soil and crop data were unavailable. However, CROPWAT model package of Food and Agricultural Organization contains these data for all ecological zones, study area inclusive. Thirty three years' climatic data of the area were inputted into the model and in conjunction with the built-in soil and crop data used to model the relationship between climatic variability and water footprint of sugarcane. Furthermore, correlation and path analyses were later used to investigate the relationship between those elements using SPSS 22 and SPSS AMOS 21 statistical packages. Results reveal that there is an evidence of climate variability in the area. Blue water footprint ( $WF_{blue}$ ) value calculated as  $172m^2/ton$  was found to be higher than Green water footprint ( $WF_{green}$ ) of  $102m^2/ton$  as well as global average of  $57m^2/ton$ , whereas the  $WF_{green}$  ( $102m^2/ton$ ) was lower than the global average ( $139m^2/ton$ ). This is an indication that sugarcane production is most dependent on  $WF_{blue}$  (irrigation). Generally, rainfall, temperature and relative humidity were found to be positively correlated with water footprint whereas sunshine and wind speed were negatively correlated. Overall, climatic factors contribute about 17%, with rainfall being most influential, to water footprint of sugarcane in the area. Despite little contribution of climatic factors to water footprint of sugarcane in the area, it is recommended that the company should institute a comprehensive water consumption scheme for the two water sources (rainfall and dam) to deal with the opposing impacts of climate variability, no matter how meager it may be.

**KEYWORDS:** Sugarcane, Climate variability, CROPWAT, Water footprint, Dangote.

## INTRODUCTION

There are earth system interactions of atmosphere, biosphere, hydrosphere and lithosphere that influence human activities. This implies that the changes in one part of the system will have a positive or negative effect on one or more other systems (IPCC, 2013). Climate change may occur over a duration of time, ranging from decades (30 years and above) to millennia. Even though, Ayoade (2003) argues that a 30 year period is not sufficient time to declare a change in climate, this change, irrespective of timeframe, may affect one or more seasons or the whole year, and involves change in one or more aspects of the weather such as rainfall, temperature or winds (Abiodun *et al.* 2011). Climatic anomalies occur when observations of substantial departures from the normal on monthly, seasonal or annual basis are made. These departures are more or less fluctuational (Adakayi, 2012).

The Intergovernmental Panel on Climate

Change (IPCC) has been at the fore front in deriving the global responses to climate change, providing predictions and projections. IPCC Working Group 1 (IPCC, 2007) acknowledged that there was a wide knowledge of the detected rise in global temperatures for some decades linked with human activities. Nevertheless, there is uneven distribution in global temperature increase. As at 2005, world average surface temperature had increased by around  $0.74^{\circ}C$  within the period 1906 to 2005. In some regions, greater change is experienced, specifically the hinterlands of continental regions such as those of the Sahel in West Africa. Besides, the increasing rate of change in the global average temperature is an indication that temperature is rising more rapidly. Significantly, this rise in the rate of change is expected to continue theoretically bringing about more speedy alterations in climate for the future. This points to the direction of a warmer earth, rising from the fact that global temperatures are set to be greater than they are at the

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moment and again because of the pressures to be applied on the available resources, sugarcane inclusive, to make sure they cater for a bigger population.

Sugarcane is one among the three most important food crops with a huge contribution to global agricultural food production. An agricultural crop like sugarcane is very water sensitive hence, the intensification of its cultivation will aggravate the over exploitation of freshwater consumption. Currently, over 70% of freshwater withdrawals are applied in agro related uses (GAIN, 2013). There is a growing competition for water resources plus the climate change on the global hydrological cycle. It is expected that the modifications in climate will restructure the patterns of demand and supply of water for both rain-fed and irrigated agriculture especially for Nigeria as one of the countries with a documented high inefficiency in water use especially for agricultural purposes (Kim, 2012). FAO (2011) also reported that increasing temperature conditions will engender increased evapotranspiration in crop, variation in yield and water productivity. Therefore, it is important that for proper adaptation in the agricultural system to changing climatic conditions, knowledge on the effects that climate will have on agricultural production and water use efficiency will be required. This forms the bases for the utilization of the water footprint (WF) concept in the study.

So far, a lot of research works exist on water footprint of sugarcane since the initial efforts made by Hoekstra and Hung (2002) to provide the first global estimation of freshwater needed to produce crops. Chapagain and Hoekstra (2004) later created the first global dataset for major agricultural products, after which, years later Mekonnen and Hoekstra (2011) improved on it. Several studies assessed the water footprint of food crops and energy crops. Chapagain *et al.* (2005) improved on the WF methodology, linking global consumption to local water resources, focusing on Spanish Tomatoes. Lindholm (2011) explored the WF of oat and other oat products for south western Finland. For Sudan, Ahmed and Ribbe (2011) attempted an assessment of water consumption of crops using the WF and virtual water concept. Kim (2012) investigated the WF for seed cotton in Turkmenistan, focusing on blue water. Specifically for energy crop, Kongboon and Sampattagul (2012) and Tiewtoy *et al.* (2013) made an assessment of water footprint for sugarcane and cassava for northern and eastern Thailand. Gerbens-Leens and Hoekstra (2009) showed that the crop WF of sugar from sugarcane is much more than that of maize and sugar beet.

All of these studies have focused on water footprint and crop production from a consumptive perspective. A gap left by these studies is the climate

change perspective from which water footprint is being affected. Not much has been done in investigating the place of climate variability as a global phenomenon on the water footprint of crops in Nigeria as a whole. This study assesses the water use of sugarcane, with particular reference to the role of climate variability (through its several factors) on water footprint of sugarcane crop for a Guinea savannah environment in the Dangote Sugar Company area. This is because water footprint as a tool is relevant in helping societies and organizations better analyse their water resource consumption behaviour in order to identify alternative levels for reducing water stress and for companies to monitor their reliance on scarce water resources along their supply chain. In the light of climate variability, the study intends to provide not only evidence for water resources and water footprint, but also new trend of thought for the development of water footprint and agro-climatology in Adamawa state.

## 2.0 STUDY AREA

The farm and factory area of Dangote Sugar Company (formerly Savannah Sugar Company) constitute the study area for this research. It is located between latitudes 9°22' N and 9°38'N and longitudes 11°45'E and 12°00'E (Figures 1 & 2). It lies at an elevation of about 150m above sea level (Mirchaulum and Eguda 1995). The company has a land mass of about 32,000 hectares, spread along Yola-Gombe highway. Farming is done through out-grower system carried out in five out-grower zone respectively and managed by estate managers. The zones include Zekun, Gyawana, Lafia, Danto and Opallo estates. Irrigation is done with the use of irrigation water from Kiri Dam (Figure 2) connected from a 30km distance canal to the sugar cane estate which commences two or three weeks after the rainfall cessation (Girei & Giroh, 2013). The area has a semi-arid climate type characterized by wide seasonal and diurnal temperature ranges. There are two main marked tropical seasons in the area. The wet season lasts from April to October and has a mean rainfall of about 905mm with its peak in August and September (Yahaya, 2013; Binbol *et al.*, 2006).

Between November and January, Harmattan dust prevails in the area and pushes the Inter Tropical Discontinuity (ITD) to its most southerly latitudinal position of 2-5°N. By this period, most of Adamawa State experiences a comparatively stable dry continental air mass from the northeast and hence rainfall is actually low (Adebayo 1999). The dry season is from November and March. The average monthly temperature is 26.9°C, with a minimum value of 18°C and a maximum of 40°C (Binbol *et al.*, 2006).

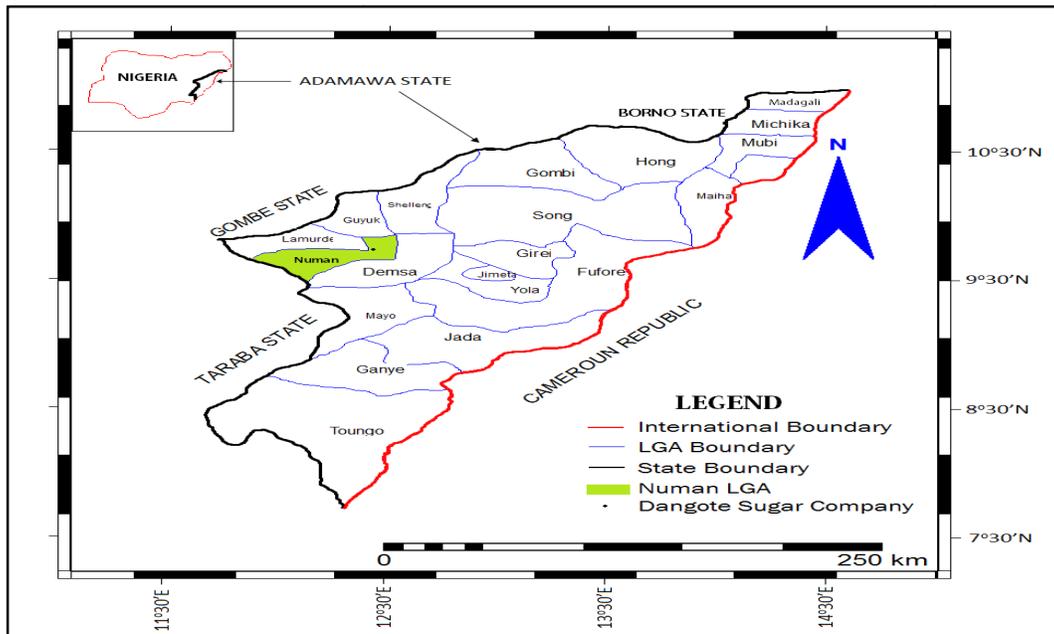


Figure 1: Location of Study Area in Numan LGA

Source: Edited from Mirchaulum (1999)

The Dangote Sugar project area exhibits a high variability in climate over an observable time period (Adebayo and Yahaya, 2015; Zemba and Obi, in press). Breaking down climatic factors of rainfall, minimum and maximum temperatures, on a temporal scale to period before and after the sugar project, a general warming and drying of the climatic environment around the study area have been identified (Zemba and Obi, in press). Rainfall was found to be declining by about 5mm/year. This is indicative of a drying period. Furthermore, Olaniran (2002) reported a 50-75mm decline in the

rainfall data of the Yola-Enugu axis from 1971-2000 and findings of Adebayo and Yahaya (2015) agree with this.

Temperature of the area is reported to have risen by about 0.841°C per decade and this development was attributed to the landuse change and other activities relating to the sugar manufacturing company (Adebayo & Yahaya, 2015). This finding supports Adebayo (2010) who found a 0.867°C rise in the temperature for Yola, Nigeria. On a global scale, Sachez-Lorenz (2009 in Adebayo & Yahaya, 2015) reported a 0.13± 0.03°C rise in mean surface temperature in over 50 years period.

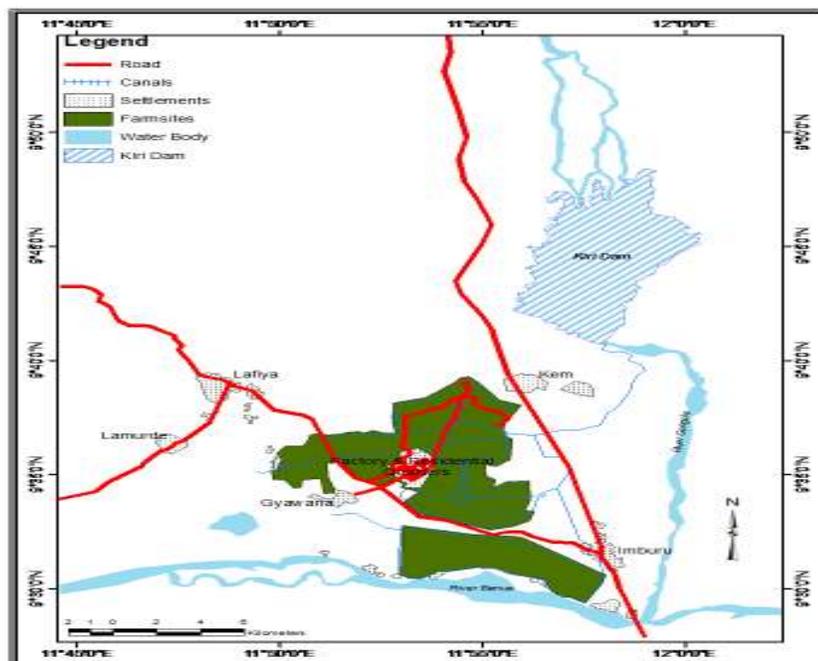


Figure 2: Study Area and Kiri Dam

Yahaya (2013) researched into climatic trends and indicated that there has been a significant variation in climate in the entire area. The independent variable of time accounts for the variation in 23% of relative humidity, 62% of evaporation, 90% of sunshine and 32% of wind run. Between the months of August/September and February/March, the relative humidity can be as high as 77.9% and as low as 16.3% respectively. Sunshine hours of 6-8hr/day are enjoyed in the area, with high wind speed of about 152 km/hr on the average (National Sugar Development Council, NSDC 2001) and mean annual evaporation is approximately 10mm.

The study area has good and favourable soil made up of alluvial and vertisol soils (Tukur and Adebayo, 1997). Gireh and Giroh (2013) reported that the vertisols of the Dangote Sugar Company, Numan are derived from quaternary alluvium underlain by the Bima sandstones found on nearby level plain. However, Mirchalum and Eguda (1995) also reported that the Dangote Sugar Company vertisols owe their origin from the olivine basalts of the Lunguda plateau. The vertisol soil is that which is present in depressions and low-lying areas and they are usually heavy-dark soils derived majorly from argillaceous sediments, rich in iron concentration with deep wide cracks when dry. This type of soil is structurally sticky, with colours between dark and gray. Virmani (1987) made reference to the high productivity of vertisols if managed properly and also their relative susceptibility to erosion. He recommended that soil and climatic parameters be studied alongside for better understanding of crop environment in the areas with vertisol. The authors noted that length of growing season is closely related to soil-water balance.

Tekwa *et al.* (2013), reported some characteristics of the soils as having a heavy presence of clay content of about 70% the vertisol soils; bulk density range from 1.25-1.40 mg/m<sup>-3</sup> in fallow soils and 1.47-1.52 mg/m<sup>-3</sup> in cultivated soils; porosity of about 43% in fallow soils and about 40% in cultivated soils; soil moisture content extending between 65% - 80%. Generally, they are regarded as difficult soils to be cultivated owing to poor drainage, low nutrient and low organic matter contents.

### 3.0 MATERIALS AND METHODS

A description of data types and sources, modeling procedures and data analytical techniques are presented in the following subsections:

#### 3.1 DATA TYPES AND MODELING PROCEDURE

The data used in this research were basically climatic, crop and soil parameters (Table 1), all of which are secondary data. These data were obtained from several sources including the Dangote Sugar Company Agriculture Department, relevant literature and the FAO CROPWAT directory contained in the package available for download on the FAO site [www.fao.org](http://www.fao.org).

Data on crop evapotranspiration and yield provide basis for the estimation of the water footprint in crop production. CROPWAT model, which is a decision support tool developed by the Land and Water Development Division of Food and Agricultural Organization (FAO), was sourced from the Food and Agricultural Organization (FAO) website and utilized to generate the reference evapotranspiration (ET<sub>0</sub> mm/day). This model applies the FAO Penman-Monteith method which is selected as the method by which the evapotranspiration of the reference surface (ET<sub>0</sub>) can be determined unambiguously also as the method which provides consistent ET<sub>0</sub> values in all regions and climates (Allen *et al.* 1998).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \dots (1)$$

ET <sub>0</sub>	reference evapotranspiration [mm day <sup>-1</sup> ],
R <sub>n</sub>	net radiation at the crop surface [MJ m <sup>-2</sup> day <sup>-1</sup> ],
G	soil heat flux density [MJ m <sup>-2</sup> day <sup>-1</sup> ],
T	mean daily air temperature at 2 m height [°C],
u <sub>2</sub>	wind speed at 2 m height [m s <sup>-1</sup> ],
e <sub>s</sub>	saturation vapour pressure [kPa],
e <sub>a</sub>	actual vapour pressure [kPa],
e <sub>s</sub> -e <sub>a</sub>	saturation vapour pressure deficit [kPa],
Δ	slope vapour pressure curve [kPa °C <sup>-1</sup> ],
γ	psychrometric constant [kPa °C <sup>-1</sup> ].

Parameters required as input in the CROPWAT package are presented in Table 1. The climatic data of rainfall, temperature, humidity, sunshine hours and wind speed for a 33 year period (1981-2013) were obtained from the Agric-Department of the Dangote Sugar Company and Yahaya (2013). Specific crop parameters of crop coefficients in different crop development stages (initial, middle and late stage), the length of each crop in each development stage, the root depth as seen in Table 1 were not all available for the sugarcane farms, hence a resort to use of data in CROPWAT package. Planting dates for the study area were adopted from Binbol *et al.* (2006). Crop coefficient (Kc) for different crop development stage and the length of growth stage were derived from FAO (2014) package. The remaining parameters were also derived from the directory of the CROPWAT package set based on Hoekstra (2003) and Allen *et al.* (1998) as carefully research information for tropical sugarcane. Soil parameters needed for a vertisol tropical soil was adopted from the directory of the CCROPWAT package set. Data on soil parameters of a black clay soil which is similar to the vertisols found on the sugarcane farms was adopted (FAO, 2014). A very essential tool for the calculation of water footprint of sugarcane is the data on yield of sugarcane (1981-2013).

**Table 1:** Type of Data Required for Inputting into CROPWAT Model

Type	Description	Unit	Data Source
Crop parameters	Crop coefficient ( $K_{c_{ini}}$ , $K_{c_{mid}}$ , $K_{c_{end}}$ )	Dimensionless	FAO, (2014)
	Length of growing season ( $L_{ini}$ , $L_{dev}$ , $L_{mid}$ , $L_{late}$ )	[days]	FAO, (2014)
	Rooting depth ( $Z_{r_{max}}$ , $Z_{r_{ini}}$ )	[cm]	FAO, (2014)
	Critical depletion	Dimensionless	FAO, (2014)
	Yield response factor	Dimensionless	FAO, (2014)
	Crop height ( $H_{max}$ )	[m]	FAO, (2014)
	Planting date	[date]	Binbol <i>et al.</i> , (2007)
Soil parameters	Total available soil moisture (FC-WP)	[mm/meter]	FAO, (2014)
	Maximum rain infiltration rate	[mm/day]	FAO, (2014)
	Maximum rooting depth	[cm]	FAO, (2014)
	Initial soil moisture depletion	[%]	FAO, (2014)
Climate parameters	Precipitation (monthly)	[mm]	Agric. Dept. DSC
	Sunshine hours (monthly)	[h]	Agric. Dept. DSC
	Humidity (monthly)	[%]	Agric. Dept. DSC
	Wind speed (monthly)	[m s <sup>-1</sup> ]	Agric. Dept. DSC
	Temperature (monthly): Maximum and minimum	[°C]	Agric. Dept. DSC

**3.2 Determination of Water Footprint**

The packages used in the analysis of the data include IBM SPSS Statistics 22, IBM SPSS AMOS 21, Microsoft Excel and CROPWAT 8.0. The impacts of climate change on the variation of WF for Sugarcane was analysed using IBM SPSS package and Microsoft Excel, to bring out temporal variations, regression and correlation outputs. SPSS AMOS 21 application was used to generate the path coefficient analysis to identify the overall contribution of climatic factors to WF sugarcane.

The FAO models of CROPWAT and AQUACROP were used to estimate crop water use. CROPWAT model is simpler to use in assessing the relationship between water availability and climate factors, hence its usage in this research. To compute the Reference evapotranspiration ( $ET_o$ ), crop evapotranspiration ( $ET_c$ ), Irrigation Requirements (IR) and Effective rainfall (Eff), the FAO 56 method (Allen *et al.*, 1998) using available climate data of the study area was adopted. The detailed procedure is as follows:

**a. Calculation of Water footprint**

The calculation procedure adopted for this study is that of Gerbens-Leenes and Hoekstra (2009) and Scholten (2009). The calculation of WF of the Sugarcane crop was done as follows:

- i. First, the green water component was calculated. This was done by determining the Crop Evapotranspiration ( $ET_c$ ) which was calculated by multiplying the Crop Coefficient ( $K_c$ ), which is dimensionless, by the reference Crop Evapotranspiration ( $ET_o$ ) (mm/day) using the Penman-Monteith method (Allen *et al.*, 1998) in CROPWAT model.

$$ET_c = K_c \times ET_o \quad \dots\dots\dots [2]$$

- ii. Next, estimation of the Green Water Evapotranspiration which is equal to the minimum of total  $ET_c$  and Effective Precipitation (Eff) and Blue Water Evapotranspiration ( $ET_{blue}$ ) was calculated according to Hoekstra *et al.* (2011) Dourte and Fraisse (2012) as:

$$ET_{green} = \min (ET_c, Eff) \dots\dots\dots [3]$$

$$ET_{blue} = ET_c - ET_{green} \dots\dots\dots [4]$$

- iii. Crop water use (CWU) is made up of the green ( $CWU_{green}$ ) and blue ( $CWU_{blue}$ ) component and is the accumulation of daily evapotranspiration over the complete growing period (Hoekstra & Chapagain, 2008). The CWU in the CROPWAT model is given in (mm) and was converted into (m<sup>3</sup>/ha) by multiplying it by the factor 10.

$$CWU_{green} = 10 \times \sum_{d=1}^{lp} ET_{green} \dots\dots\dots [5]$$

$$CWU_{blue} = 10 \times \sum_{d=1}^{lp} ET_{blue} \dots\dots\dots [6]$$

Therefore, to calculate the green and blue component of the water footprint of the sugarcane (m<sup>3</sup>/ton), the crop water use was divided by the yield (Y, ton/ha):

$$Green\ Water\ Footprint\ (m^3/ton) = \frac{CWU_{green}(m^3/ha)}{Y\ (ton/ha)} \dots\dots [7]$$

$$\text{Blue Water Footprint (m}^3\text{/ton)} = \frac{CWU_{\text{blue}} \text{ (m}^3\text{/ha)}}{Y \text{ (ton/ha)}} \dots\dots [8]$$

The green and blue water are the major sources of crop water. Therefore, the grey water was not considered. This was due to unavailability of adequate data. The volume of the diluted water due to pollution by chemicals such as phosphorus, potassium etc. is still open for research and can be a subject of future investigations. Average water footprint for sugarcane was obtained by summing up the average green and blue WF of sugarcane for the area of study.

$$\text{Water Footprint} = \text{Green Water Footprint} + \text{Blue Water Footprint} \dots [9]$$

The result was compared with the global average generated by Mekonnen and Hoekstra (2011) and other sources to be able to place the status of the result for the study area. The green and blue water footprint results were subjected to trend analysis, equations and coefficient of determination ( $R^2$ ) to analyze its variability over time.

### 3.3 Investigation of the Relationship Between Climate and Water Footprint

To explore the relationship between climate factors and water footprint of sugarcane, correlation and path coefficient analysis were utilized. This also was to identify the contribution of the climatic elements to the overall water footprint of sugarcane crop in the Dangote Sugar Company.

Path analysis is an extension of the regression model, used to test the fit of a correlation matrix with a causal model that has been tested (Garson, 2004). It was first defined by Wright (1921; 1934) as a means of deciding on the influence of independent factors on dependent factors. The aim of path analysis is to provide estimates of the magnitude and significance of the hypothesized causal connections among sets of variables, in this case sugarcane and climatic factors, displayed through the use of path diagrams. There are three interrelated components in path analysis (Bollen, 1989):

- (i). the translation of a conceptual problem into pictorial presentation, which shows the network of relationships;
- (ii). Obtaining systems of equations that relate observed correlation and covariance to parameters; and
- (iii). Decomposition of effects of one variable on another (that is, direct, indirect and total effects) from the correlation of measured variables.

Path analysis was conducted by considering the  $WF_{\text{green}}$ ,  $WF_{\text{blue}}$  and  $WF$  as observed endogenous variables respectively while climatic factors were the observed exogenous variables. The correlation coefficient as an imperative statistical indicator was also

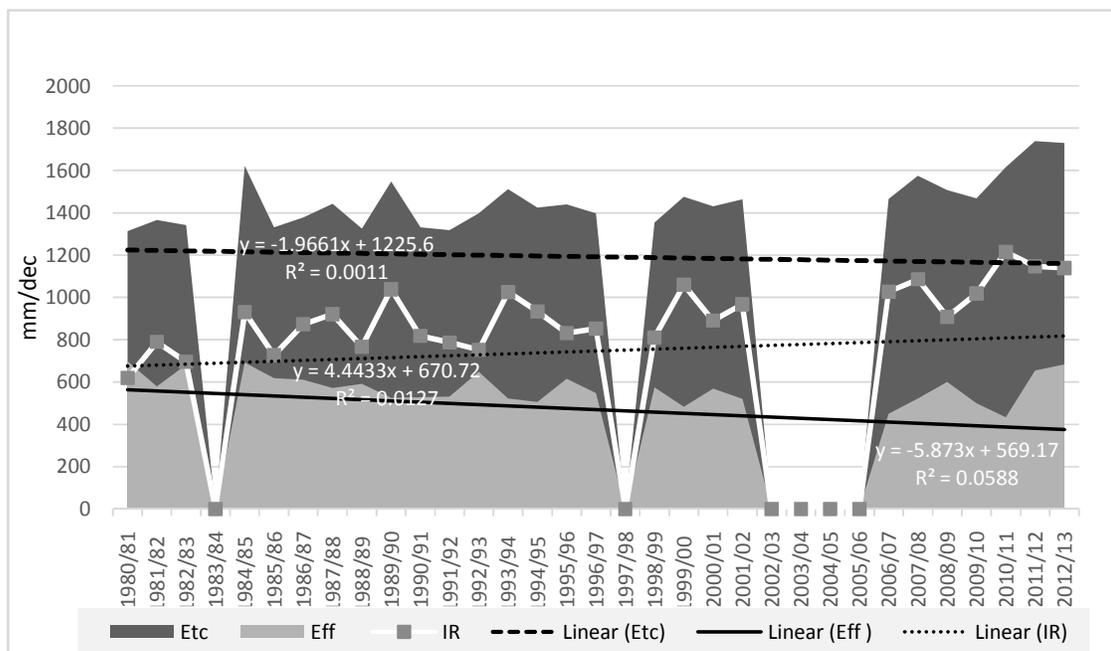
applied. The chi-square statistics, the normed fit index (NFI) and root mean square error of approximation (RMSEA), which are all included in the path analysis were used to estimate model fit. In this method of analysis, the Chi-square tests the null hypothesis that the over-identified (reduced) model fits the data just as does a just-identified (full, saturated) model fits the data. In the case of a just-identified model, there is a direct path (not through an intervening variable) from individual variables to other variables. Wuensch (2014) pointed out that for such a model, the chi-square will always be equal to zero because the fit will always be perfect. When one or more of the paths is deleted, one get an over-identified model and the value of the chi-square will increase, except the deleted path(s) have coefficients of zero exactly. In a situation where a nonzero path is removed, it will reduce the fit of model to data thus, increasing the value of this chi-square. Conversely, if the fit is reduced by merely a small amount, one will have a better model in the sense of it having less complexity and explaining the covariances almost as well as the more complex model (Wuensch, 2014). The larger the probability related to the chi-square, the better the fit of the model to the data (Melessa and Zewotir, 2013). The NFI tests the hypothesized model alongside a reasonable baseline model which ideally should be 1.0. For a good fit, a model should have a RMSEA of  $< 0.10$  and  $< 0.05$  as very good, while  $< 0.01$  is considered as beautiful fit. Path significance was centred on the critical ratio (CR). In absolute value, a  $CR > 2$  is considered as significant (Melessa and Zewotir, 2013).

## 4.0 RESULTS AND DISCUSSION

For ease of reference and convenience, results of this research are presented in subsections as follows:

### 4.1 Climate and Water Footprint

The result of impact of climate variation (Crop Evapotranspiration, Effective Rainfall and Irrigation Water Requirement) on water footprint indicates that the climatic elements of rainfall, temperature (minimum and maximum), relative humidity, wind speed and evaporation, which have varied over a period of time has been playing a significant role in water footprint of sugarcane. Crop evapotranspiration and Effective rainfall, for instance, have a declining trend of 0.1% and 6% respectively while Irrigation water requirement showed an increasing trend of 1.3% (Figure 3). Green water footprint has a value of 102  $\text{m}^3\text{/ton}$ , while blue water footprint stands at 172  $\text{m}^3\text{/ton}$  and the total water footprint is 274  $\text{m}^3\text{/ton}$ . The blue water footprint calculated for the study area as compared to the global average (57  $\text{m}^3\text{/ton}$ ) is way higher. Also, it's higher than those of northern Thailand with 87 $\text{m}^3\text{/ton}$ , (Kongboon & Sampattagul 2012) and India with 104 $\text{m}^3\text{/ton}$  (Gerbens-Leenes & Hoekstra, 2009) (Table 2).



**Figure 3:** Interannual Variability of Crop Evapotranspiration (ET<sub>c</sub>), Effective Precipitation (E<sub>eff</sub>) and Irrigation Water Requirements (IWR) of Sugarcane

**Table 2:** Global and DSC Average Water Footprint of Sugarcane

	Sugarcane (m <sup>3</sup> /ton)			
	Green WF	Blue WF	Grey WF	Total
DSC, Numan	102	172	-	274
Global average*	139	57	13	210

This result seems to agree with Kim (2012) that Nigeria is one of the countries in the world ranking high in water footprint, especially for agricultural production due to inefficient use of water. Reliance on irrigation water from the Kiri dam as a source of water may be the reason for the fluctuations observed in planting dates from the inception of the factory between March and June. Not so much cognizance is observed to be taken of length of rainy season in the scheduling of crop planting and growth periods.

**4.2 Relationship between Climatic Variations and Water Footprint of Sugarcane**

Assessing the relationship between variation in climate elements and water footprint of sugarcane was the primary goal of this study. The independent variables included in the study were the five major climatic variables of rainfall, temperature, relative humidity, wind speed and sunshine. This was achieved using the correlation and path analysis. Table 3 shows the results of the correlation analysis as described in this section. The correlation analysis among WF<sub>blue</sub> of sugarcane and climatic factors indicated that rainfall, relative humidity and sunshine hours were positively correlated with WF<sub>blue</sub>, with relative humidity reaching a statistically significant level (p < 0.05). Conversely, temperature and wind speed were negatively correlated. From the correlation among WF<sub>green</sub> of sugarcane and climatic factors, only rainfall and relative humidity

indicated a positively correlation with rainfall reaching a statistically significant level (p < 0.05). On the contrary, temperature, sunshine and wind speed were negatively correlated.

Total water footprint for sugarcane in the area of study was positively correlated with rainfall, relative humidity and sunshine, while negatively correlated with temperature and wind speed. Of all the climatic elements, rainfall reached a significant level at p < 0.05, signifying it as the most influential on water footprint of sugarcane. However, this may not necessarily be the case in all regions. Sun *et al.*, (2012) for instance discovered that temperature and wind speed were the most influential on WF of spring wheat among the climatic factors, in an irrigation district in China. That part of China, the Hetao Irrigation district is located in a semi-arid region, amenable to the possible effect of climate change.

**4.3 Path Analysis Results of the Relationship between Climate and WF**

The statistical significance of individual parameter estimates for the paths in the fitted model is one of the vital measures to be considered. The significance can be seen by calculating the critical values, which are obtained through dividing the parameter estimates by their respective standard errors. The computed critical ratio values together with the corresponding p-values are presented in Table 3. For

Figures 4, 5 and 6, the probability associated with the chi-square in the path analysis procedure is 0.860 which is  $> 0.05$ . This shows that the model is better fit to the data. The RMSEA value of 0.000 indicates that the

models are a good fit because they are lower than 0.01. The NFI default and saturated model value of 0.999 and 1.000 for each of the models indicate that the model for Figures 4, 5 and 6 are ideal.

**Table 3:** Regression Weights for Relationship between WF<sub>blue</sub>, WF<sub>green</sub> and Climatic Factors

A	Relationship	Maximum likelihood estimates	Standard error (S.E)	Critical ratio (C.R)	P-value
	WF <sub>blue</sub> <--- WindSpeed	-0.397	0.949	-0.418	0.676
	WF <sub>blue</sub> <--- Sun	-0.898	39.742	-0.023	0.982
	WF <sub>blue</sub> <--- RH	7.155	5.713	1.252	0.210
	WF <sub>blue</sub> <--- Temp	4.697	29.553	0.159	0.874
	WF <sub>blue</sub> <--- Rainfall	0.157	0.142	1.106	0.269
B					
	WF <sub>green</sub> <--- WindSpeed	-0.484	0.517	-0.936	0.349
	WF <sub>green</sub> <--- Sun	-20.998	21.656	-0.970	0.332
	WF <sub>green</sub> <--- RH	2.047	3.113	0.658	0.511
	WF <sub>green</sub> <--- Temp	6.707	16.104	0.416	0.677
	WF <sub>green</sub> <--- Rainfall	0.144	0.077	1.863	0.062

The other issue considered at this stage was the magnitude and direction of the parameter estimates. In Figure 4, all the path coefficients were positive except wind speed, showing that there is a positive relationship between WF<sub>blue</sub> and the individual climatic variables except wind speed. Part A of Table 4 suggests that the most important variable to explain climatic influence on WF<sub>blue</sub> is relative humidity. Sunshine hours were observed to have no influence on WF<sub>blue</sub> going by its value of -0.005 standardized regression coefficient. The effect of sunshine hours on WF<sub>blue</sub> can be ruled out. The results also showed that the exogenous variables of climate explained 17% of the WF<sub>blue</sub> variance observed.

Figure 5 indicates the existence of a positive relationship between WF<sub>green</sub> and climatic elements of rainfall, temperature and relative humidity while holding a negative relationship with sunshine hours and wind speed (part B of Table 4). This is suggestive of rainfall being the most significant path coefficient to explain WF<sub>green</sub>. It is also estimated that the exogenous variables of climate all together explains 22% of the

WF<sub>green</sub> variance. In other words, the error variance of WF<sub>green</sub> is approximately 78% of the variance.

From Figure 5 the results indicate a positive relationship between WF and the climatic variables of rainfall, relative humidity and temperature and a negative relationship with sunshine hours and wind speed as given in the C part of Table 4. This is suggestive of rainfall being the most significant path to explain the influence of climatic elements on WF of sugarcane for the study area. This agrees with Ahmed and Ribbe (2011) who analyzed water footprint of crops in Sudan. They authors attributed the variation in green water footprint to variability in rainfall and agricultural practices. From the results of this research, it was also estimated that the exogenous variables of climate explained 17% in all of WF variance. In other words, the error variance of WF is 83% of the variance. In order of priority, the climatic variables with the most effect on WF of sugarcane include rainfall, relative humidity, temperature, sunshine and wind speed.

**Table 4: Standardized Regression Weights**

A	Relationship		Estimate
WF <sub>blue</sub>	<---	Wind Speed	-0.075
WF <sub>blue</sub>	<---	Sun	-0.005
WF <sub>blue</sub>	<---	RH	0.260
WF <sub>blue</sub>	<---	Temp	0.034
WF <sub>blue</sub>	<---	Rainfall	0.219
<b>B</b>			
WF <sub>green</sub>	<---	Wind Speed	-0.161
WF <sub>green</sub>	<---	Sun	-0.205
WF <sub>green</sub>	<---	RH	0.132
WF <sub>green</sub>	<---	Temp	0.085
WF <sub>green</sub>	<---	Rainfall	0.356
<b>C</b>			
WF	<---	Wind Speed	-0.108
WF	<---	Sun	-0.079
WF	<---	RH	0.218
WF	<---	Temp	0.053
WF	<---	Rainfall	0.274

Comparatively, the two methods of correlation and path analysis (Table 5) have unanimously indicated that climatic factors of rainfall and relative humidity have been identified as playing the key roles in influencing water footprint of sugarcane. Path analysis however went a step further to estimate that climate alone impacts water footprint by only 17%, which is relatively small. This means that climate is not the only factor causing the increasing trend in WF of sugarcane for the

study area. Based on this, the results suggest that water footprint of a crop may not be primarily dependent on climatic factors and their variations, even though they may contribute to a certain extent. Other factors like crop characteristics and agricultural production system (Kongboon & Sampattagul 2012; Sun *et al.* 2012) are suggested to be contributing majorly as well. This will make up for the other 83% as mentioned earlier.

**Table 5: Impact of Climatic Variables on Water Footprint Using Correlation Analysis and Path Analysis**

	Rainfall		Temperature		Relative humidity		Sunshine hours		Wind speed	
	Corr	Path	Corr	Path	Corr	Path	Corr	Path	Corr	Path
WF <sub>blue</sub>	0.325	0.22	-0.044	0.03	0.355*	0.26	0.102	0.00	-0.101	-0.07
WF <sub>green</sub>	0.403*	0.36	-0.188	0.08	0.204	0.13	-0.157	-0.21	-0.248	-0.16
WF	0.361*	0.27	-0.098	0.05	0.307	0.22	0.008	-0.08	-0.157	-0.11

\* Correlation significant at  $p < 0.05$ ; Path = path analysis; Corr = correlation analysis

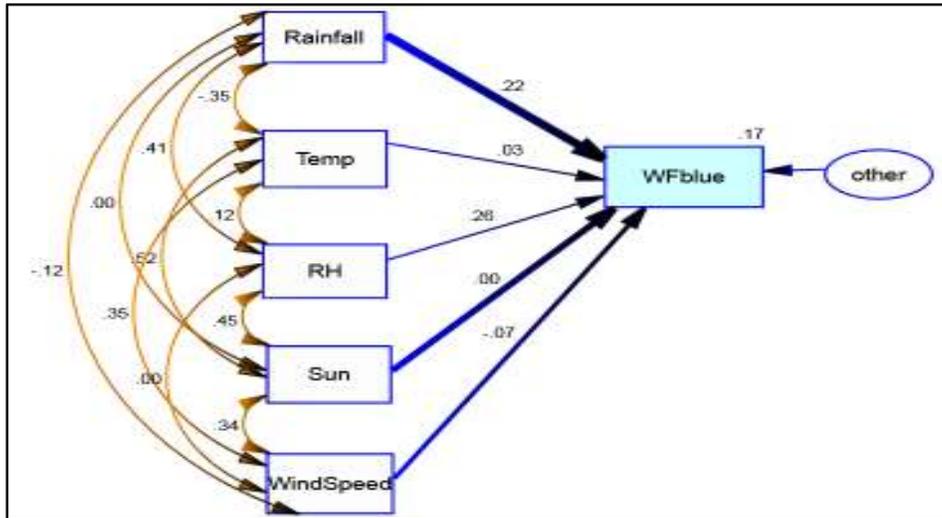


Figure 4: The Effect of Climatic Factors on Blue Water Footprint (WFblue) of Sugarcane. RH = Relative Humidity; Temp = Temperature; Sun = Sunshine

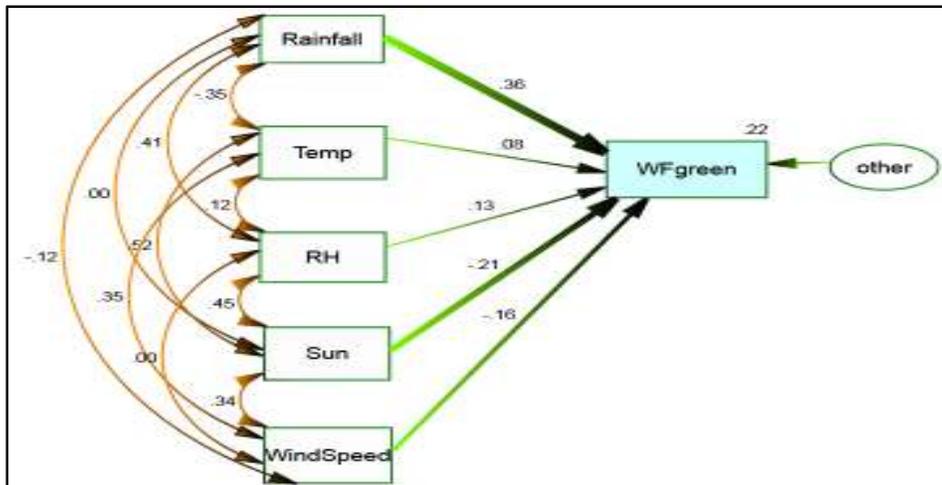


Figure 5: Path Diagram Showing the Effect of Climatic Variables on Green Water Footprint (WFgreen) of Sugarcane. RH = Relative Humidity; Temp = Temperature; Sun = Sunshine hours

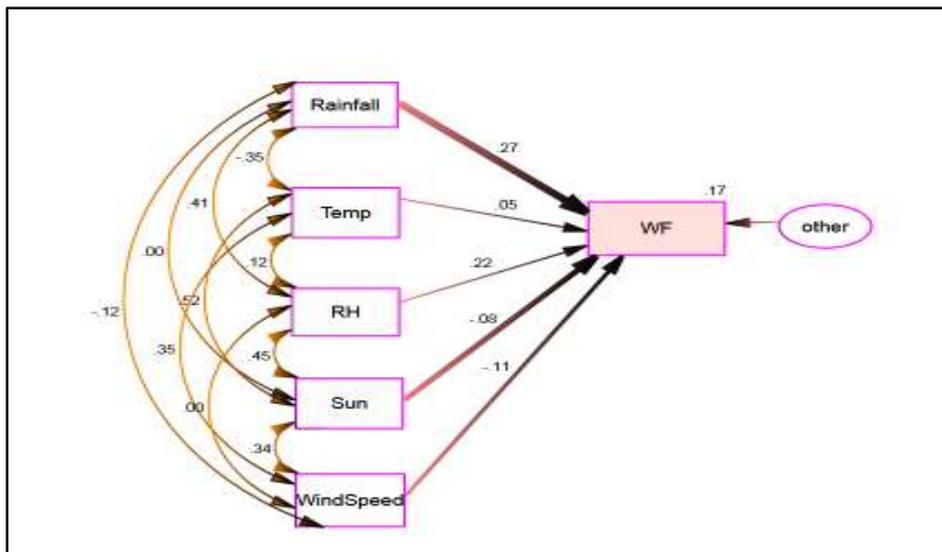


Figure 5: Path Diagram Showing the Effect of Climatic Variables on Water Footprint (WF) of Sugarcane. RH = relative humidity; Temp = Temperature; Sun = Sunshine hours

## CONCLUSION

The findings of this research revealed that WF blue accounted for a larger proportion of the total water footprint of sugarcane than WF green. This means that growing of sugarcane in the study area depends on the blue water source (irrigation water). The green water however has a lower opportunity cost than the blue water (Aldaya *et al.*, 2010; Hoekstra *et al.*, 2011). Rainfall was observed as the most influential climatic element on the water footprint of sugarcane for the study area. However, Adebayo and Yahaya (2015) and Zemba and Obi (in press) noted an average 5mm yearly decline in rainfall for the same area. This is a cause for concern since the main source of blue water for the Sugarcane production that is the Kiri dam is from the River Gongola, a major tributary to Benue River. This, coupled with the fact that there is an observed decrease in rainfall totals along the Benue River basin, which has affected the rate of discharge of water and an increase in run off during the rainy season, wastes away unutilized makes water availability lower. The direct and indirect implications of these may cumulate to a disadvantage for the production of sugarcane as it requires a lot of water to survive especially under a changing climate.

Even though, the climatic factors were found not to be dominant factors that caused increase of WF of sugarcane in the area over the study period (1981-2013), its contribution of 17% is significant enough to attract efforts towards mitigating its adverse effects in the long run. Results further suggested that the water footprint of a crop also depends on crop parameters and agricultural production level rather than the local climate condition alone.

## RECOMMENDATIONS

On the basis of the findings of this research, the following recommendations are made

- i. Availability of accurate data was a major limitation in this research. As a result, the use of simulation technique to make up for the missing climate data was adopted. There was also an observed lack of proper documentations in the area of water resource and agricultural management. This threatens to good analysis, monitoring and evaluation for the company. More priority should be given to ensuring the adequacy and accuracy of data by the company as first beneficiaries of most of the research findings in the area.
- ii. Irrigation schedules need to be upgraded by adjusting planting timing, method and volume of water utilized. Resorting to rainwater harvesting from runoff discharged during rainy seasons and recycling of polluted water may be beneficial in maximizing yield.
- iii. Climate change and variation alters water resources availability, for instance, changing rainfall patterns and increasing rates of evapotranspiration. Meaning that rain water may not suffice for the cultivation of sugarcane in the area, thus requiring irrigation. Therefore, it is practicable to recommend that the company should institute a comprehensive water

consumption scheme for the two water resources (of both rain and dam) to deal with the opposing impacts of climate change no matter how meager using this study and others as a baseline for further studies to save water.

- iv. Results indicate that climatic factors were not the only factors causing the increasing trend in sugarcane water footprint during the study period. This is indicative of the fact that the water footprint is quite dependent on agricultural management rather than by the agro-climate and its variation alone. Therefore, better management of the applied agricultural inputs utilized for cultivation and an improvement in the farm practices should be adopted.
- v. Under a changing climatic condition, more efficient adaptation strategies may well be pursued and their performance measured by way of objective indicators like the water footprint and other related indexes. Some of these strategies could include modification of sowing dates, use of different cultivars that are more drought resistant, etc.
- vi. It is believed that prediction of future water footprint trend based only on climatic factors may be misleading. This is because this study showed that there are other factors affecting the water footprint of sugarcane. Therefore, other environmental and agro-managerial factors should be taken into consideration when studying water footprint.

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