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Influence of Some Climatic Variables on Runoff in Ajali River Nigeria

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Abstract: *The linearity of hydro-climatic relations is required to analyse the dependence of streamflow on some climatic variables. This study is focused on evaluating the relationship and significance of average annual climatic variables in estimating annual runoff in Ajali River located in Enugu State, Nigeria. 1983-2006 records of annual climatic and runoff data are used to develop multiple linear regression (MLR) model, expressing the annual runoff as a function of the annual climatic variables. In addition, hypotheses are tested using t-test and one-way ANOVA. At 0.05 level of significance, the results revealed that the model was not statistically significant in predicting runoff in Ajali River basin. MLR model evaluated as* $Q = 2.81 I^{0.024} S^{-0.037} H^{-0.055} W^{-0.028} R^{0.096} T_s^{0.172} E^{-0.111} P^{0.016}$, *revealed a non-linear relationship between runoff and the climatic system while the multiple coefficient of determination,* R^2 *is estimated as 0. 228, meaning that climatic variables account for 22.8% of the variation in runoff. Also, the significant test revealed that none of the climate variables is a significant predictor of annual runoff (p > 0.05) in Ajali watershed. Based on the findings, it can be deduced that non-climatic factors such as human activities, account for 77.2% of the annual runoff variation in the watershed. To ensure sustainable water supply in the study area, efforts should be geared towards the control of human activities in the river basin.*
Keywords: *climatic variables, runoff, multiple linear regression.*

1. INTRODUCTION

Water is unarguably the requisite natural resource to drive sustainable social and economic development. In the context of global climate change, it is expedient to decode the sensitivity of streamflow, as a source of water supply, to variations I climate. Pragmatic approaches for the determination of influence of climate on runoff is often viewed as a laborious task due to extensive field investigation involved. Furthermore, the intricacies involved in measuring these hydrological parameters varies spatially, although in some cases may also vary temporarily [1]. Since the essence of climate-runoff modelling pervades the underlying description of hydro-climate processes, which is vital in hydrological designs, it is important to investigate the governing principle of climate-runoff relation. To analyse the relationship between hydrologic and climatic system, it has been the convention to use statistical approaches. As a standard for modelling hydrologic and climatic variables, pair-wise correlations between the time series data of hydrologic and climatic variables are computed [2]. In that case, the strength of the relationship between the variables is based on the value of the correlation coefficients [3]. As a statistical approach, the multiple linear regression (MLR) model has proved to be very reliable in climate-runoff modelling [2,3].

In many studies, there have been emphasis on the temporal relationship between runoff and climate. In this regard, [8] developed a multiple linear regression model for hourly runoff in Waingang River sub-basin, China. The results revealed that as the lead-time increased in all the three models developed, the model accuracy decreased except for four-hourly forecast. In another related study, using MLR approach, [9] confirmed that while the collective month-wise model was valid, the individual month-wise model was not valid in modelling climate-runoff relations in Swat River basin. Also, when MLR model was explored by [10] in highly glacierised Himalayan basin, to correlate discharge and meteorological variables, discharge was observed to be highly correlated with precipitation (r=0.350), especially in June, then July with the lowest correlation in August. MLR was used by [11] in the Qira River basin in Kulun Mountains, Xinjiang, North-west China, to relate runoff to temperature and precipitation. The result however was in line with those of [10] such that runoff related positively with precipitation, while temperature related negatively with runoff. In the large Himalayan basin, [12] also used MLR to show that daily discharge was a first-order Markov chain and discharge-temperature correlation decreased with increase in time-lag.

While most of these studies considered temporal climate-runoff models, the non-temporal MLR has been neglected in addressing the climate-runoff relation. Even when [13] attempted to explore the mechanisms and characteristics of hydro-climatic processes, the linearity exemplified by MLR was ignored, thus casting doubts on the detailed understanding the climate-runoff processes. In order to address these gaps in Knowledge, this study is set out to ascertain the non-temporal linearity between runoff and climatic variables, using the MLR model. As an application, the annual runoff and climatic data of River Ajali in Enugu State, southeast Nigeria, was used to calibrate and validate the MLR model.

2. METHODOLOGY

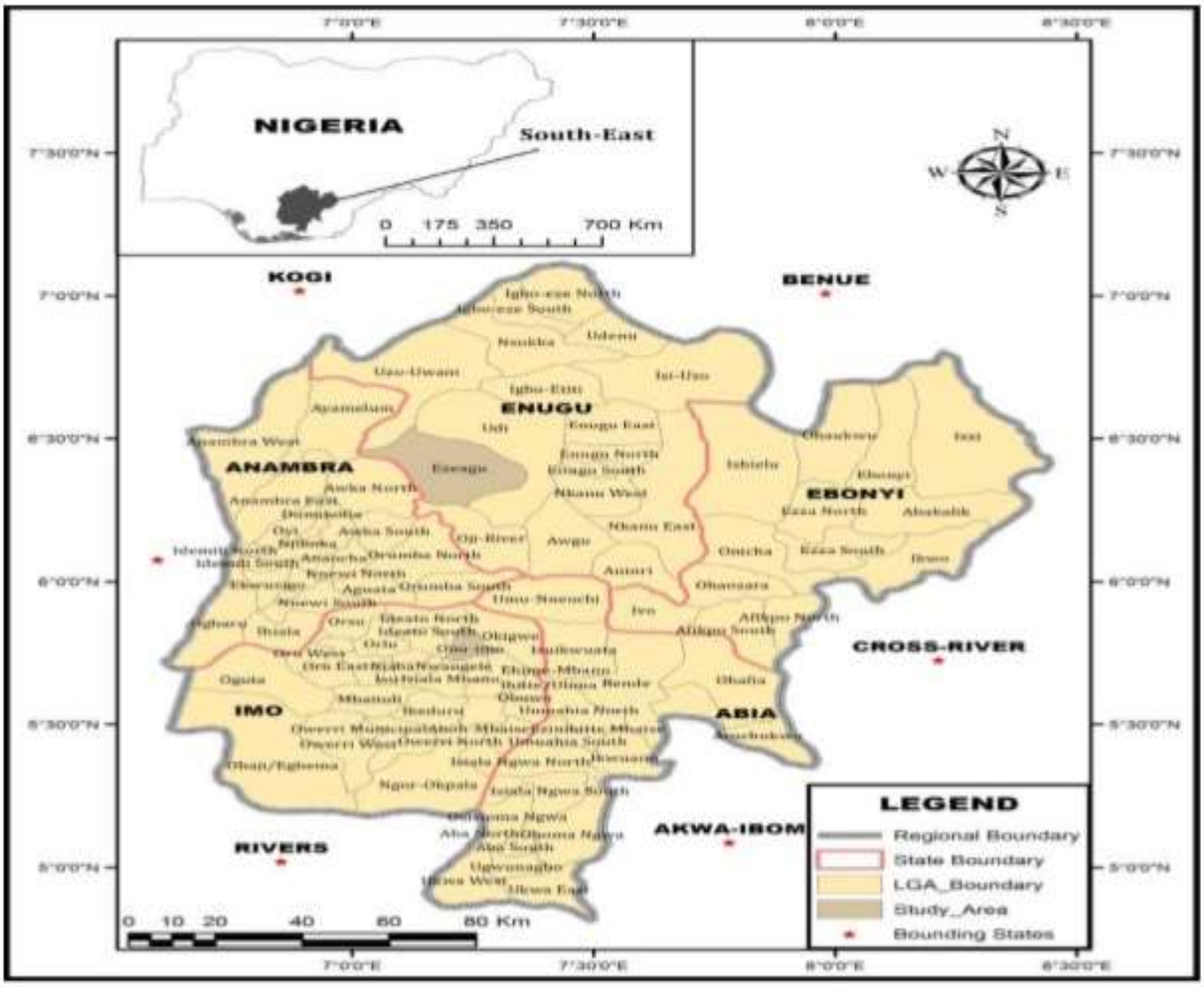

Figure 1: Map of South eastern Nigeria showing the Ajali watershed in Ezeagu (Source: [9])

2.1 Study Area

Figure 1 shows the location of Ajali River watershed at Aguobu Umumba in Ezeagu North, Ezeagu Local Government of Enugu State, southeast Nigeria. It is located at Latitude 6028”0’N to 6016”0’N and Longitude 706”0’E to 7024”0”E and an elevation of 52m [9].The general topography and geology of the zone made the state highly prone to gully erosion phenomenon and with mean annual rainfall of 2000mm [10]. As shown in Figure 2, the Ajali River Aguobu Umumba watershed is predominantly underlain by Ajali and Nsukka Formations at upland and Mamu Formations in the lowlands. The poorly sorted Ajali Sandstones are easily washed away by concentrated runoff from prolonged and torrential rainfall. The soil of the study area is sandy with small percentage of silt/clay [10]. [11] reported that Ajali river is a major source of drinking water and other domestic uses to Ajali and Ezeagu communities as well as Enugu State Water Corporation’s major supply source to Enugu urban dwellers in Nigeria. Nigerian Breweries and 7-Up company, Enugu, Nigeria, have continued to discharge treated and or untreated liquid effluents and or solid wastes emanating from their production processes and operations into the Ajali River in Enugu state. The farmlands are being ravaged by erosion due to collapsed aeration pond of the companies’ effluent water and burst underground pipes that channel these effluents from these factories down to Ajali River. The main occupation of these surrounding communities which is farming has been thrown out of business. [11] claimed that this led to the destruction/disruption of their socio-economic and cultural lives, since they have abandoned the use of the river because of adverse health implications due to your effluent pollution into the river.

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They now resort to private water supply tankers for their daily water supply at astronomical costs, thus aggravating their poverty index and making their lives unbearable. There is also depletion of aquatic life in Ajali due to unfavourable condition arising from effluent water discharged into the river. Most importantly, the river is rapidly becoming shallow. One wonders if the fast decrease in the depth of the river is as a result of these activities or due to climatic influence.

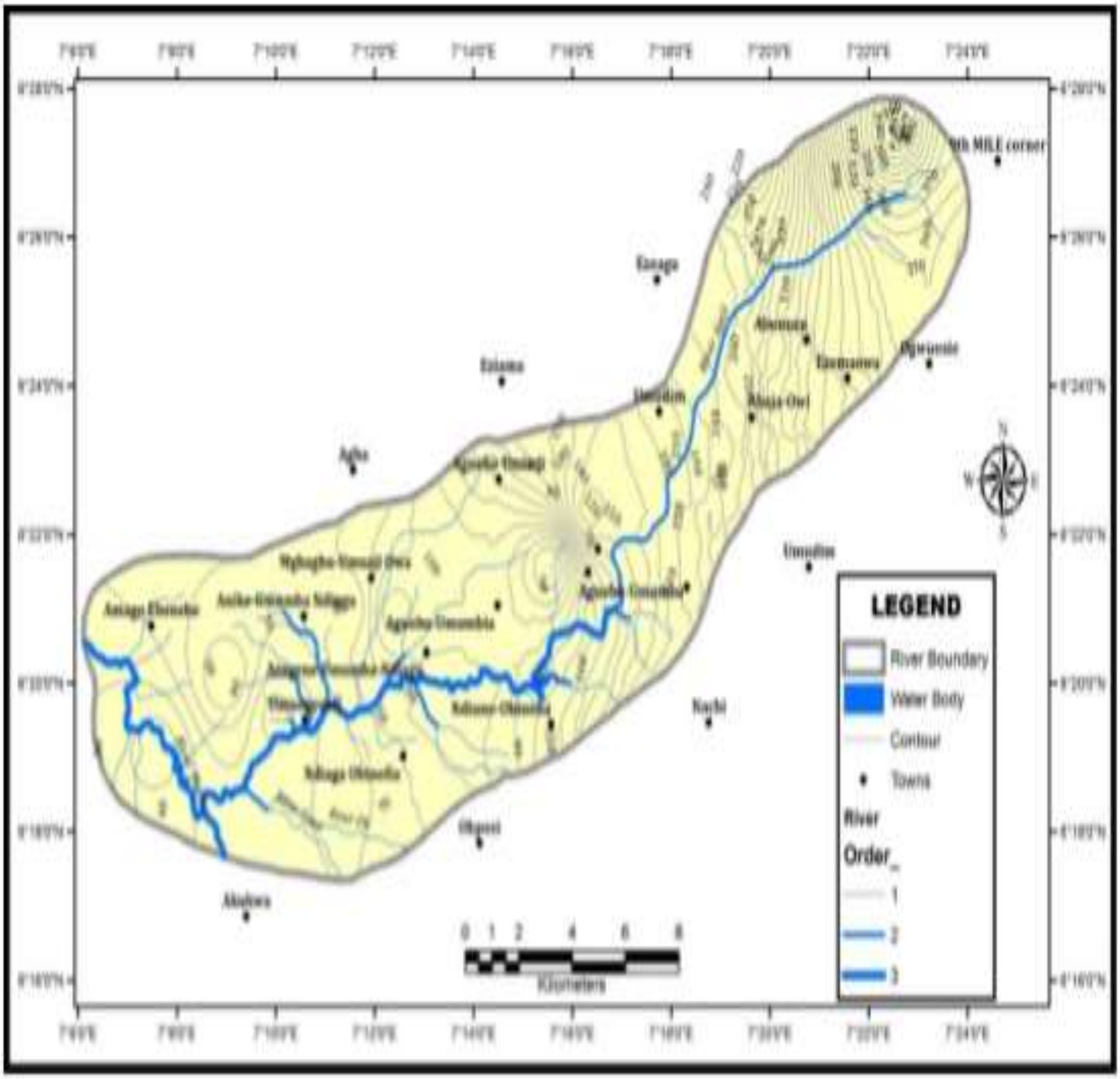

Figure 2: Map showing Ajali Watershed, Aguobu-Umumba, Ezeagu, Enugu State (Source: [9])

2.2 Sources and Method of Data Collection

Monthly discharge records to be used cover over 33 years of Ajali river basin. Discharge data was obtained from the Anambra-Imo River Basin Authorities. Monthly rainfall depth, average air temperatures, sunshine hours, evaporation, humidity, wind speed, soil temperature, cloud cover, solar radiation and atmospheric pressure data for Enugu were obtained from the Nigerian Meteorological Agency (NIMET), Oshodi Lagos, Nigeria. NIMET is the agency responsible for the measurement, control, and storage of the hydro-meteorological data in Nigeria. All monthly data were all averaged to obtain annual average for all the climatic data available and these are presented in Table 1.

2.3 Formulation of Flood Model for Enugu

[12] defined a multiple linear regression model as

$$Y_i = \beta_0 + \beta_1 X_1 + ... \beta_k X_{ik} + e_i \quad (1)$$

and suppose that n observations on the variables y, x_1,..., x_k are available, which are indexed by i=1,.,n . Then, the n realizations of the relationship can be written in the following form:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} 1 & x_{11} & \cdots & x_{1k} \\ 1 & x_{21} & \cdots & x_{2k} \\ \vdots & \vdots & & \vdots \\ 1 & x_{n1} & \cdots & x_{nk} \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_k \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{bmatrix} \quad (2)$$

ε_i ~iid N(0, σ^2), β_0 is the intercept (multi-dimensionally), β_1, β_2,… β_{k-1} are the regression coefficients for the explanatory variables, $X_{i,k}$ is the value of k_{th} explanatory variable for the i th case. Using the explanatory variables of discharge, Q at the gauging station as: rainfall depth, I, maximum and minimum Air Temperatures, T, Sunshine Hours, S, Evaporation E, Humidity H, Wind Speed, W, Soil Temperature T_s, Cloud Cover, Solar Radiation, R, and Atmospheric Pressure, P and applying the multiple regression method, the explanatory variables related with discharge as follows:

Table 1: Input Variables for Flood Model of Ajali River, Awka

YEAR	Evaporation (mm)	Sunshine (hours)	Solar Radiation	Rainfall (mm)	Air Temperature (ºC)	Wind speed (Km/hr)	Relative Humidity (%)	Soil Temperature (ºC)	Discharge (m^3/s)
1983	4	5.3	12.1	131.8	26.65	4.1	68	26	12.65
1984	3.9	5.7	12.9	173.9	26.5	3.4	73	25.4	12.24
1985	3.8	5.4	12.4	171.1	26.3	3.4	75	25.1	12.61
1986	3.7	5.5	12.7	155.8	26.175	3.6	73	25.6	12.55
1987	4	5.8	13.8	156.7	26.9	3.6	74	26.1	12.61
1988	3.9	5.3	12.6	151.7	26.65	3.5	75	25.9	12.55
1989	3.9	5.8	13.6	162.2	26.35	3.6	68	25.5	11.80
1990	3.8	5.2	12.9	175.7	26.7	3.8	74	25.9	12.27
1991	3.7	5.4	12.8	171.1	26.15	3.7	77	25.3	12.44
1992	3.8	6	12.7	149.3	26.1	3.8	71	25.2	12.62
1993	3.9	5.7	12.6	170.7	26.2	3.6	74	25.4	12.61
1994	3.9	5.3	12.7	162.8	26.1	3.7	72	25.3	12.68
1995	3.9	5.6	12.8	179	26.35	3.6	75	25.6	12.61
1996	3.8	5.4	12.5	182.8	26.3	3.7	78	25.4	12.68
1997	3.8	5.2	12.7	184.6	26.25	3.5	74	25.4	12.60
1998	3.9	5.6	12.6	165.8	26.8	3.6	70	26.4	12.63
1999	3.7	5.4	12.5	171.4	26.3	3.4	76	25.8	12.59
2000	3.9	5.5	12.8	165.4	26.5	3.5	72	25.7	12.63
2001	3.9	5.8	12.5	170.7	26.55	3.6	73	25.8	12.60
2002	3.9	5.3	12.6	170.4	26.6	3.7	72	25.8	12.54
2003	3.9	5.2	12.3	170.6	26.7	3.7	74	26	12.66
2004	3.8	5.3	12.5	172	26.6	3.7	74	26.1	12.66
2005	3.8	5	12.6	161.8	26.75	3.7	73	26.3	12.66
2006	3.8	4.9	11.9	180.6	26.7	3.8	73	26.3	12.52

$$Q = \alpha_0 * I^{\alpha_1} * S^{\alpha_2} * T^{\alpha_3} * E^{\alpha_4} * H^{\alpha_5} * W^{\alpha_6} * R^{\alpha_7} * {T_s}^{\alpha_8} \quad (3)$$

2.4 Model Solution

Taking the logarithm to base 10 of both the left- and right-hand sides of Equation 3:

$$\log_{10} Q = \alpha_0 + \alpha_1 \log_{10} I + \alpha_2 \log_{10} S + \alpha_3 \log_{10} T + \alpha_4 \log_{10} E + \alpha_5 \log_{10} H + \alpha_6 \log_{10} W + \alpha_7 \log_{10} R + \alpha_8 \log_{10} T_S \quad (4)$$

In matrix form, Equation 4 can be represented as a multiple linear regression model:

$$Y_{(n\times 1)} = X_{(n\times(k+1))}\,\beta_{((k+1)\times 1)} + \varepsilon_{(n\times 1)} \quad (5)$$

To find estimates of $\hat{\beta}$ [i.e. α_i; i = 0 to 8)], the sum (s) of derivation between the predicted values and the observed values would be minimized to obtain the least square curve as:

$$\hat{\beta} = (X^T X)^{-1} X^T Y \quad (6)$$

The SPSS statistical software was used for graphical plots and regression analysis to estimate the coefficients of the response function, Q. The significance of the explanatory variables and model equation was examined by analysis of variance (ANOVA) at 95% confidence intervals (CI). In addition, model, predictions were carried out to validate the statistical model.

2.5 Model Verification

To verify the model, after the model has been developed, the model was used in runoff prediction of the catchment using climate data and compared with the measured values in order to ascertain the model performance. The model prediction was evaluated using the Coefficient of Determination (R^2) defined as follows:

$$R^2 = \left[\frac{\sum_{i=1}^{n}(Q_i - \bar{Q})(\hat{Q}_i - \tilde{Q})}{\sqrt{\sum_{i=1}^{n}(Q_i - \bar{Q})^2(\hat{Q}_i - \tilde{Q})^2}}\right]^2 \quad (7)$$

where Q_i is the observed discharge, $\hat{Q}_i$ is the predicted discharge, $\bar{Q}$ is the mean of the observed discharges, $\tilde{Q}$ is the mean of the predicted discharges and n is the length of the observed/ predicted series. The coefficient of one (R^2=1) indicated that the regression line perfectly fitted the observed data [14].

2.6 Test of Model Significance

By comparing probability (p) values greater than the Fisher's F exact test, the significance of the model at a confidence level of 95% was obtained by the analysis of variance (ANOVA). The "Prob >F" less than 0.05 indicated that model was significant. Especially larger F-value with the associated P value (smaller than 0.05, confidence intervals) means that the model was effective with less error [15]. The results of the analysis of variance are summarized in Table 3.

3. RESULTS AND DISCUSSION

The estimates of regression coefficients were substituted into Equation 3 to obtain the climate-flood model of Ajali river as:

$$Q = 2.81 I^{0.024} S^{-0.037} H^{-0.055} W^{-0.028} R^{0.096} Ts^{0.172} E^{-0.111} P^{0.016} \quad (8)$$

The non-linearity in the climate flood model as shown in Equation 8 is consistent with the findings of [16] who identified a non-linear relationship between runoff and the climatic system.

3.1 Results of Significance Tests of Model

Two types of test on the model, namely; individual test (t-test) and joint test (F-test) were conducted. F-test for Model was used to test whether any of the independent variables are linearly associated with *Y*. The T- test involved testing whether an explanatory variable has any influence on the dependent variable when the other explanatory variable is held constant. The result for the significance of the entire climate-flood model is presented in Table 2. Table 2 shows that the multiple regression analysis indicates that the climate-flood model of River Ajali was not statistically significant in predicting annual runoff (sig < 0.05) with significant F value of 0.69.

Table 2: ANOVA of Climate-Flood Model for Ajali River, Awka

Model		Sum of Squares	df	Mean Square	F	Sig.
$Q = 2.81 I^{0.024} S^{-0.037} H^{-0.055} W^{-0.028} R^{0.096} T_s^{0.172} E^{-0.111} P^{0.016}$	Regression	0	9	0	0.69	0.710
	Residual	0.001	21	0		
	Total	0.001	30			

At 0.05 level of significance (p<0.05), the results of t-test and the corresponding level of significance of the independent input variables of the climate-flood models for River Ajali is presented in Table 3. As shown in Table 3, none of the climate variables is a significant predictor of annual runoff (p > 0.05) in Ajali watershed. Furthermore, it implied that none of the climate variables has effect on runoff variation in Ajali watershed.

3.2 Result of Model Validation

Figure 3 shows that the climate-flood model for River Ajali, climatic variables explain only 22.8% of the annual variation in runoff. The stream gauging station of Ajali at Aguobu-umumba in Anambra state is located at the center of the city. Ajali river at Aguobu-umumba is the water intake for potable water supply to Ajali, Ezeagu towns and environs. This is a huge burden to the river as the increasing water demands of the cities may have been causing huge variations in annual runoff other than climate (77.2%=100% - 22.8%).

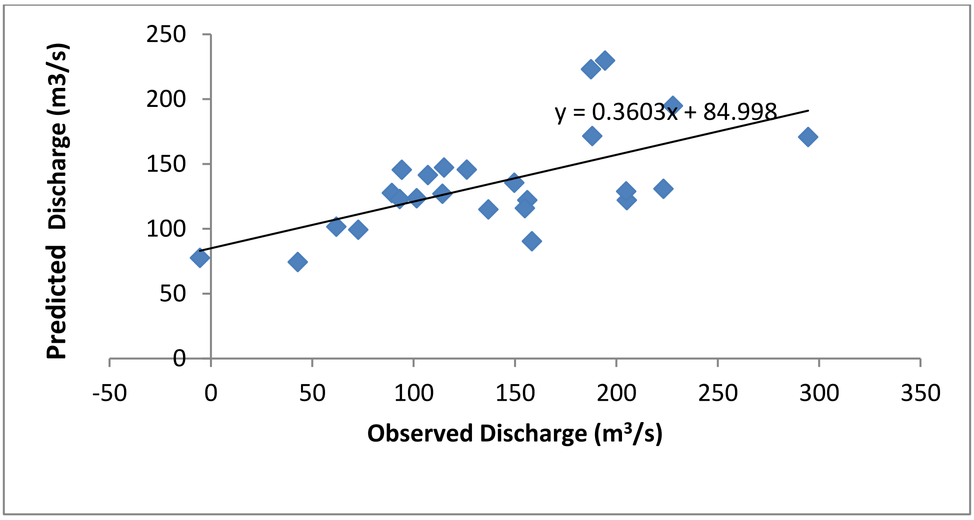

Figure 3: Validation of Flood Model of Discharge of Ajali River

Table 3: Statistical Significance of Climate Variables in Flood Model of Ajali River

Variable	Coefficient	Std. Error	T	Sig	Partial
(Constant)	0.449	0.598	0.751	0.461	
Average Air Temperature	0.625	0.384	1.626	0.119	0.334
Rainfall depth	0.024	0.028	0.872	0.393	0.187
Sunshine Hours	-0.037	0.044	-0.849	0.406	-0.182
Relative Humidity	-0.055	0.08	-0.688	0.499	-0.148
Wind speed	-0.028	0.032	-0.894	0.381	-0.192
Soil Radiation	0.096	0.167	0.572	0.573	0.124
Soil Temperature	-0.172	0.373	-0.461	0.65	-0.1
Evaporation	-0.111	0.204	-0.543	0.593	-0.118
Atmospheric Pressure	0.016	0.114	0.138	0.892	0.03

This observation indicates that the runoff variation in River Ajali is largely influenced by non-climate factors. In Ajali area, economic development and population growth have increased sharply the demand for water resources, which directly decreased river runoff amount. Total water consumption in Ajali from 1980 to 2008 showed a gradual increasing trend. The increase in industrial water consumption was the lead cause of the increase in total water consumption. Therefore, it can be concluded that the influence of human activities on the runoff is the maximum possible factor influencing annual runoff in these areas. This is consistent with previous study by [17] who used linear regression to separate and quantify the two driving forces on annual runoff variations, and showed that 78.6% of annual observed runoff and 72.9% of natural runoff decreases could be explained by climate change.

4. CONCLUSION

In this study, the influences of climate on runoff were modelled using multiple regressions and the non-linearity between runoff and the climate was confirmed. It can be concluded that the influence of human activities on the runoff is the maximum possible factor influencing annual runoff in the area. The result demonstrates that identifying internal drivers of runoff variability can improve an understanding of long-term runoff-climate dynamics at a catchment scale and predicting regional water availability.

5. RECOMMENDATIONS

Although this study provides useful regression model for the forecasting of flows for River Ajali using climatic data, it is believed that improved forecasts may still be achieved by the use of more sophisticated modelling techniques such as physically-based models or artificial neural network models may be used. These provide a huge potential for the simulation of the non-linear behaviour of hydrological systems and it may be advantageous to use a distributed hydrological model rather than the statistical approach used. However, it is not entirely clear non-climatic factors are directly responsible for changes in runoff and water availability in the watershed. Continuous direct observations of runoff and its indicators will be a clue for unveiling the relationship between the annual runoff and non-climatic factors. To ensure sustainable water supply in the study area, it is recommended that stakeholders should intensify efforts towards ensuring adequate control and management of human activities in and around the river basin.

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