AN EVALUATION OF RAINFALL AND DISCHARGE RELATIONSHIPS IN THE RIVER KILANGE CATCHMENT, ADAMAWA STATE, NIGERIA

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This work was done in collaboration among all authors. Author DMS, performed the statistical analysis and wrote the first draft of manuscript. Author EY, contributed in fieldwork observation and data collection, and author AMM designed the study and approved the final manuscript. All authors together read the manuscript and have no conflict of interest.

ABSTRACT

Rivers play a very important role in economy and agriculture, but due to climate change and improper management, river catchments are losing their natural water recharge capacity. This study was undertaken to find out the trends and variability of rainfall and discharge at the Malabu section of River Kilange. Rainfall and discharge time series data (1987 to 2013) have been analyzed in this study. Pearson's Product Moment Correlation was used to assess the association between mean monthly rainfall measured through conventional method and Internet-based rainfall data at Yola and Malabu respectively. Relationship assessment between rainfall and discharge was also done by undertaking Pearson's Coefficient of Correlation. It was found that mean monthly rainfall and discharge were strongly and positively correlated (r = 0.873, P=0.001). Analyses of 27 years data (1987 to 2013) indicate annual mean rainfall for both Yola and Malabu stations are characterized by downward trend, whereas the mean annual discharge for the same period at the Malabu hydrologic station showed upward trend. Climate change and improper land management may have influenced the present condition, where the long-term rainfall and river discharge indicate uneven trends. It is therefore recommended that landuse management strategies be put in place to curtail further environmental degradation in the River Kilange catchments.

KEY WORDS: *Discharge, Kilange, paired samples test, Pearson's Correlation and rainfall.*

INTRODUCTION

Rainfall and river discharge have an intricate relationship as exhibited by the hydrological cycle, in which water in liquid, solid or gaseous form flows continuously between the earth's surface and the atmosphere. Rainfall, which constitutes the main form of precipitation in the tropics falls on the ground and arrive at a stream channel through several pathways. The proportion of rainfall that does not evaporate or percolate into the ground flows over the soil surface as surface runoff, whilst the remainder infiltrates through the soil and flows beneath the surface to a stream as sub-surface flow (Nicandrou, 2010). Large amounts of surface runoff can only occur when the rate of rainfall exceeds the infiltration capacity of the soil. The portion of surface runoff, sub-surface flow and underground flow that eventually enters the stream channel and flow therein which, is referred to as stream flow or river discharge is the focus of this study.

The reliable prediction of the various hydrological parameters including runoff and sediment yield for remote and inaccessible areas are tedious and time consuming by conventional methods. In many parts of the world, and this is particularly true for the developing countries, gauging networks in river catchments are in decline as a result of lack of financial and human resources (Margaretha, 2009). In Nigeria, one of the major problems of hydrological studies and water resources planning and management is that of generating adequate hydrological data for use by water resource managers and researchers (Ezemonye and Emeribe, 2013). This development has made hydrological research very difficult in the country. The situation has made many researchers in the country to abandon hydrological studies in favour of other aspects of the study (Oruonye *et al*., 2016). To overcome this problem of inadequate meteorological and hydrological data, suitable methods of study have to be developed for the river catchments concerned, such as the River Kilange.

Discharge and stage height are often found to be empirically related and this relationship can be elucidated using a rating curve. River discharge is normally expressed in terms of water level variations using mathematical formula or calibrated relationships, referred to as rating curves. A rating curve is established by simultaneous measurements of velocity and water levels, and a curve is fitted through the measured hydraulic variables (Tarpanelli *et al*., 2013). By using the prediction curve, one can simply take the gauge reading and estimate the river discharge (Gnacadja, 2013).

The Study Area

The River Kilange catchment covers an area of 4955 km2 encompassing parts of Fufore, Girei, Gombi, Hong, Maiha, Mubi-North, Mubi-South and Song Local Government Areas of Adamawa state Nigeria. It is located between latitudes 9° 23´ 26" N to 10° 19´ 00" N and longitudes 12° 15´ 00' E to 13° 17´ 25" (Fig. 1).

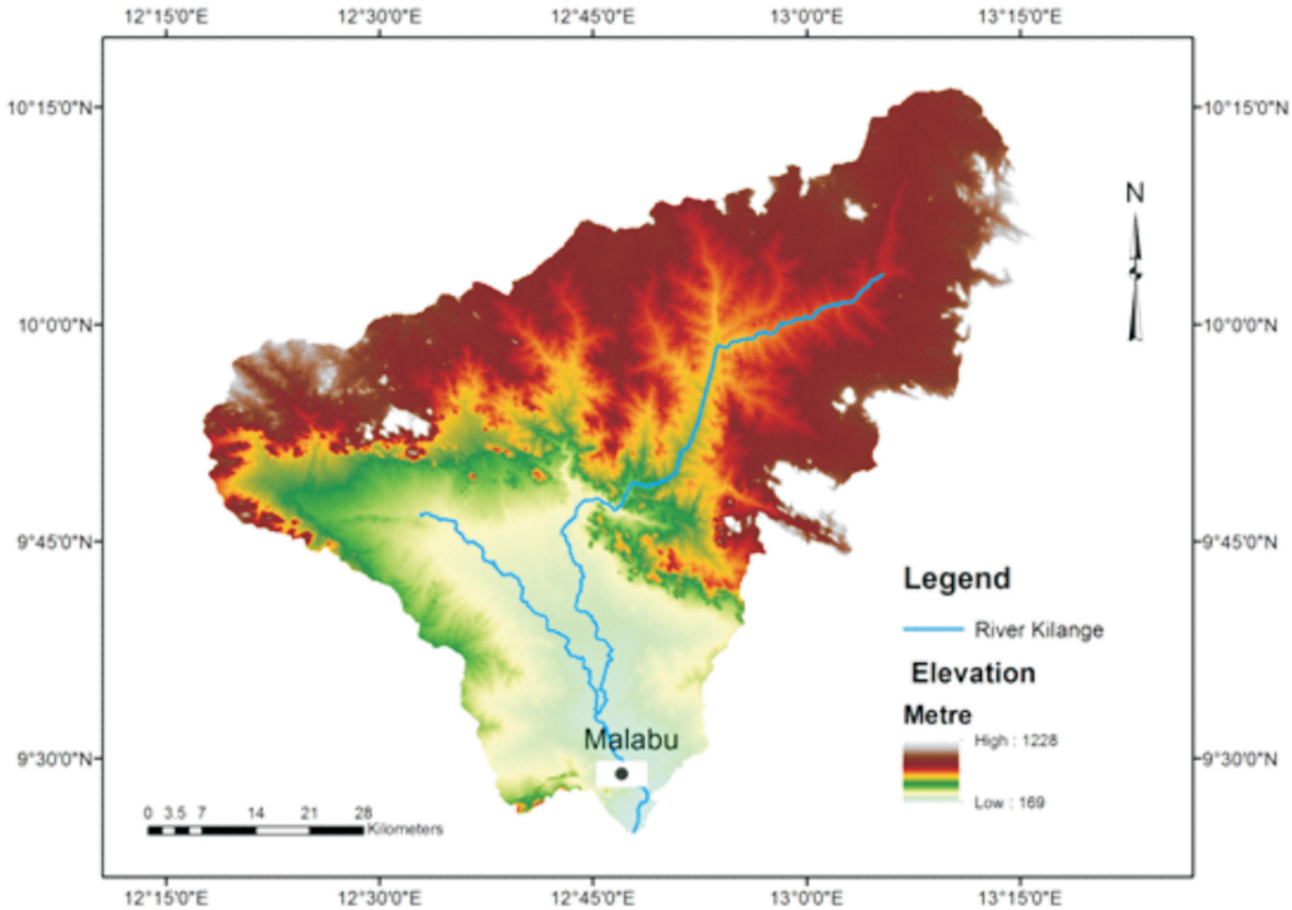

Figure 1: The River Kilange Catchment
Source: Arc-GIS 10 Analysis

The River Kilange catchment area is underlain by granitic crystalline rocks of the Pre-Cambrian Basement Complex. Overlying the older Basement Complex are the sedimentary and volcanic rocks of relatively younger age ranging from the upper Cretaceous to Quaternary periods (Bawden, 1972; Pell, Frischmann & Partners-PFP-Nigeria, 1981). Elevation in the River Kilange catchment ranges from 169 Metres to1228 Metres above mean sea level. The highest points are confined to the peaks of hills in headwater areas, while the low plains bordering the flood plains of the River Benue into which the River Kilange discharges its water constitute the lowest levels. The major drainage feature in the study area is the River Kilange, which originates from the hills bordering the northern extreme of the catchment. Major tributaries of River Kilange are the Rivers Loko and Song draining the western portion, whereas the eastern part is drained by numerous minor tributaries, prominent among, which are Mayo-Nguli and Giraba. The central part of the study catchment is drained by River Sangannare. The River Kilange drains into the River Benue at an outlet near Wuro-Bokki, a settlement located some 45 kilometres upstream of the bridge at Jimeta (Pell, Frischmann &Partners-PFP Nigeria, 1981). The River Kilange catchment lies in the Sub-Sudan climatic zone. The months from May to October constitute the rainy season, while the months from November to April make up the dry season period. Mean annual rainfall in the study area is about 900 mm based on data for the years1987 to 2013.

Temperature in the study area is characterised by little diurnal, monthly and seasonal variations. The hottest period in the year is in the month of April, with temperatures rising to 37o C and 39.6o C in the northern and southern extremes of the study area respectively (Adebayo, 2004). December and January constitute the coldest months when temperatures drop to 15.3o C and 18.3o C in the northern and southern extremes of the study area respectively. The dominant soil types in the River Kilange catchment are sandy loam to sandy clay with or without concretionary iron pan. The weakly developed soils of erosion and non leached ferruginous tropical soils dominate the northern part of the Kilange catchment. These occur as shallow skeletal soils on the upper slopes with deeper colluvial soils in the valleys. The middle portion of the Kilange catchment is dominated by rock outcrops, raw mineral soils and weakly developed soils of erosion. These are shallow, skeletal soils over granite, basalt, sandstone and ironstone. The southern segment of the Kilange catchment comprises of sandy loam and clay loam with varying degrees of concretion (Bawden, 1972). Adamawa State and River Kilange catchment inclusive is located within the Sudan Savannah belt of Nigeria (Adefioye, 2013). The natural vegetation of River Kilange catchment is very lightly wooded characterized by sparse, relatively short 5-10 metre semi-deciduous trees with shrubs and grasses constituting the dominant cover. The upland pediments are characterized by shrub savannah (PFP-Nigeria, 1981). Near the towns, the native species of trees are gradually being replaced by some exotic species. Agriculture is the major source of livelihood for the majority of people in the study area. Two basic patterns of rain-fed agriculture are practiced in the area in relation to the two fundamental soil types, the residual upland pediment soils and alluvial floodplain soils. Maize, guinea corn, cowpea, millet, groundnuts and cassava are the main crops grown on the upland pediment soils. The alluvial floodplain soils are more fertile than the upland soils and are, therefore more productive and in addition are better supplied with and better able to retain moisture. For these reasons, the floodplains are relatively more extensively cultivated and to a certain extent on a more permanent basis in respect to individual plots. The apparent pattern of cultivation observable in the floodplain areas is that, rice, sugar cane and banana are planted in the poorly drained areas, while maize, guinea corn, cassava and a variety of mixed vegetables including onions and okra are restricted to the better drained sites (PFP-Nigeria, 1981).

Materials and Methods

Two sources of rainfall data were used in the analysis. The first dataset was obtained from the Nigeria Meteorological Agency-NiMeT at Yola. The second set of data was the Climate Forecast System Reanalysis - CFSR daily time series data from the Internet. Both the NiMeT and CFSR rainfall datasets were for 27 years (1987 to 2013).

Rainfall data measured through conventional method was compared with the Internet- based (CFSR) rainfall data to determine the correlation between the two. The result of this comparison formed the basis for adoption of the web-derived data for application in this study. The most recent CFSR rainfall data was for the year 2013. The other datasets used in the analysis, namely: river stage, stream discharge and the conventional rainfall data were, therefore streamlined to the same time period. The Malabu CFSR rainfall station was selected because of its proximity to the Malabu section of the River Kilange, where the river stage and field measurement data were taken for this study. Mean monthly rainfall for the Malabu and Yola stations along with the river discharge have been summarized (Table 1).

Table 1: Summary of Monthly Mean Values of Rainfall and Discharge for the River Kilange (1987-2013)

Month	NIMET-Rainfall	CFSR-Rainfall	Discharge (m3/sec)
January	0	0	4
February	0	0	5
March	4.84	0.15	5
April	37.49	13.98	8
May	91.46	68.84	13
June	128.38	93.31	19
July	171.07	147.44	27
August	192.79	174.58	40
Sepetember	180.49	112.5	47
October	56.19	55.48	26
November	0.45	0.41	6
December	0	0.01	5

Source: NiMet, UBRBDA Yola; and Internet (2018).

Stream discharge was measured through both direct and indirect methods. In the direct method, flow velocity and flow cross-sectional area were directly measured in the field. For the indirect method of river discharge measurement, a two-step procedure was followed. First, the stage-discharge rating curve was plotted using historic gauge height data (called stage) for the Malabu hydrological station. In the second step, the discharge was estimated by using the previously established stage-discharge relationship.

The river stage was plotted in Microsoft Excel Spreadsheet against the corresponding estimated river discharge in an arithmetic plot with stage as ordinate (Y axis) and discharge as abscissa (X axis). After plotting the stage versus discharge to the arithmetic scale, a smooth curve through the plotted points is drawn (Fig.2).

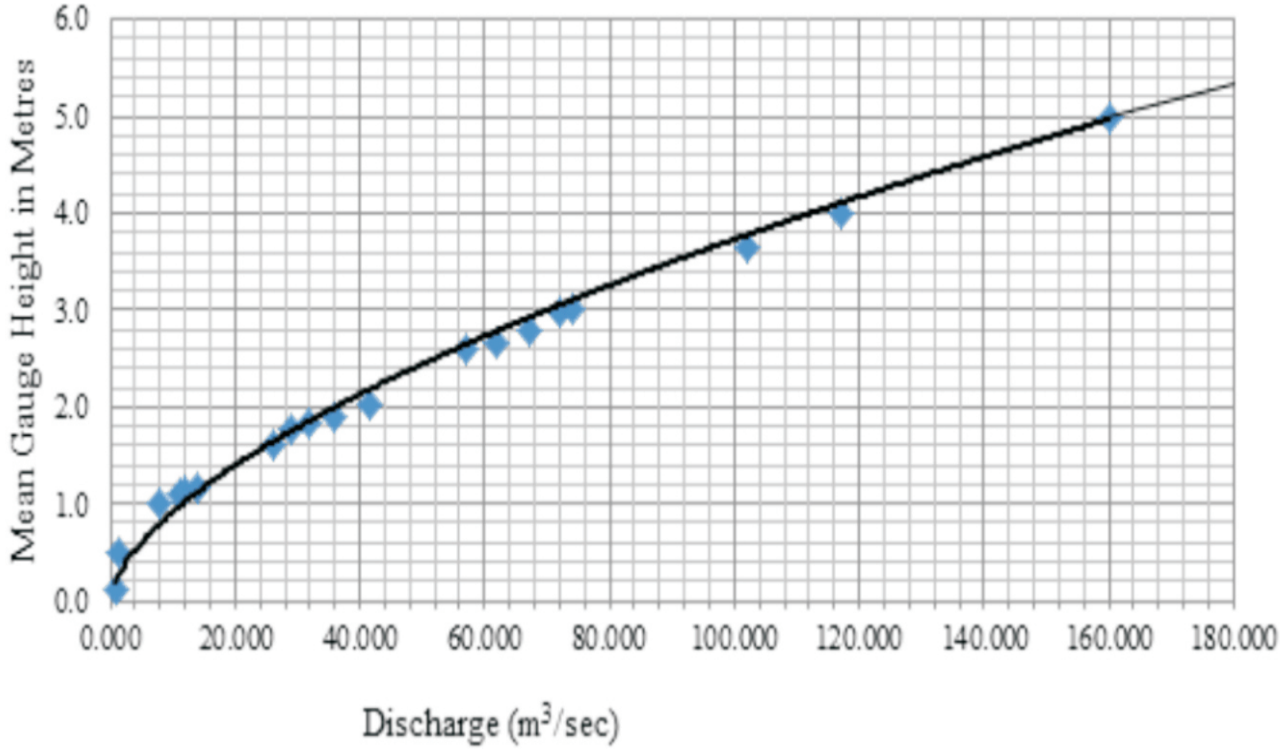

Figure 2: Stage-Discharge Rating Curve for the River Kilange at Malabu

Results and Discussions

In this section, mean monthly discharge and rainfall time series were analysed to better understand their relationships, and to evaluate the consistency of the data used. The mean monthly rainfall at Yola (NiMeT) measured through the conventional method was compared with the Web-based (CFSR) rainfall at Malabu. The Malabu hydrological station is located on the River Kilange about 45 kilometres upstream of the River Benue.

Mean monthly rainfall values between Malabu and Yola stations were strongly and positively correlated ($r = 0.977$, $P=0.001$) as shown in (Table 2).

Table 2: Correlation Coefficient of Monthly Mean Rainfall for Malabu and Yola

Correlations			
		Yola	Malabu
Yola	Pearson Correlation	1	0.977**
	Sig. (2-tailed)		0.001
Malabu	Pearson Correlation	0.977**	1
	Sig. (2-tailed)	0.001	
	N	12	12

**. Correlation is significant at the 0.05 level (2-tailed).

The very close association between mean rainfall values for Malabu and Yola suggests that data from either of the two weather stations can be used for this study. Similarly, the Malabu weather station at which rainfall data were derived through non-conventional measurement methods (Climate Forecast System Reanalysis-CFSR) can be considered fit for meteorological and hydrological analysis. This finding corroborates Dile (2014) and Fuka (2013) who assert that the web-based weather data can be used for analyses, particularly in data-scarce river catchments. The CFSR rainfall data for Malabu weather station was therefore used to analyse rainfall-discharge relationships in this study.

The linear relationship between rainfall values for Malabu and Yola stations is shown in scatter plot (Fig. 3).

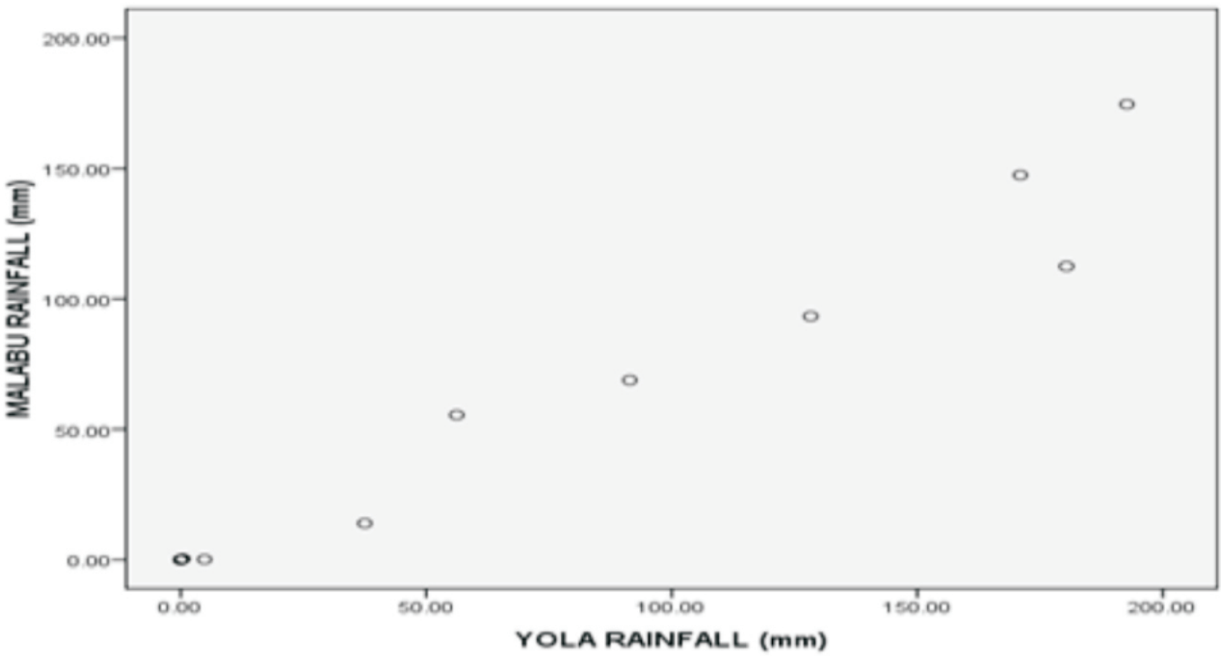

Figure 3: Scatter Plot for Malabu and Yola Mean Rainfall (1987-2013 Data)

The scatter plot (Fig. 3) exhibited a linear trend and the correlation was found to be significant (Table 2). This finding reveals the plausibility of the Climate Forecast System Reanalysis-CFSR rainfall data for meteorological and hydrological analyses, especially in data-scarce river catchments like the Kilange.

Analysis of mean monthly rainfall and discharge at Malabu station on the River Kilange revealed that highest values occurred in the months of August and September respectively (Fig. 4). The River Kilange is characteristically perennial at the Malabu section. River discharge though scanty persists at the Malabu reach of the River Kilange even in the dry season months (January to March and December) when no rainfall is recorded (Fig. 4).

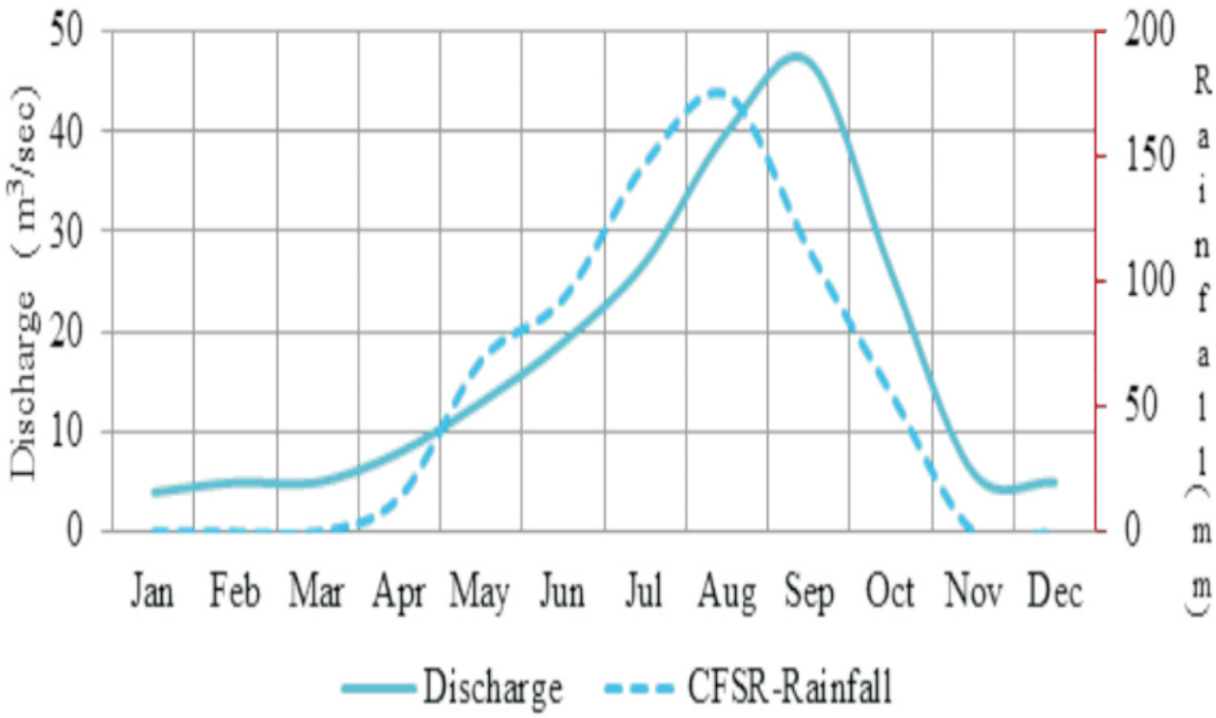

Figure 4: Annual Trend of Mean Monthly Rainfall and Discharge for River Kilange Catchment (1987-2013).

Pearson's coefficient of correlation was conducted to measure relation between both mean monthly rainfall and mean monthly discharge values for the River Kilange catchment. Significance of correlation becomes evident when P-value is lower than α (=0.05) and insignificance of correlation becomes evident when P-value is higher than α (=0.05).
As shown in (Table 3), mean monthly rainfall values and discharge for the River Kilange catchment were strongly and positively correlated (r = 0.873, P = 0.001). The correlation is also significant since the P-value (0.001) is less than (0.05). The Pearson correlation of 0.873 is close to +1, which indicates strong and positive relationship. This rainfall-discharge relation is typical of most tropical rivers, where the influence of ice or snow on the transformation of rainfall to stream flow is non-existent or negligible.

Table 3: Correlation Coefficients of Monthly Mean Rainfall and Discharge for the River Kilange Catchment.

		RAINFALL	DISCHARGE
RAINFALL	Pearson Correlation	1	0.873**
	Sig. (2-tailed)		0.001
	N	12	12
DISCHARGE	Pearson Correlation	0.873**	1
	Sig. (2-tailed)	0.001	
	N	12	12

Analyses of mean annual rainfall and discharge time series revealed there is a steady increase in river discharge despite the decrease of rainfall during the study period (1987 to 2013) as shown in (Fig. 5). This finding corroborates Okechukwu *et al*. (2010) who assert that a phenomenon known as "Sahelian Paradox" has started to manifest in the Sudan Savanna zone of Nigeria. The "Sahelian paradox" is an environmental phenomenon characterized by a steady increase in stream flow without commensurate increase in rainfall.

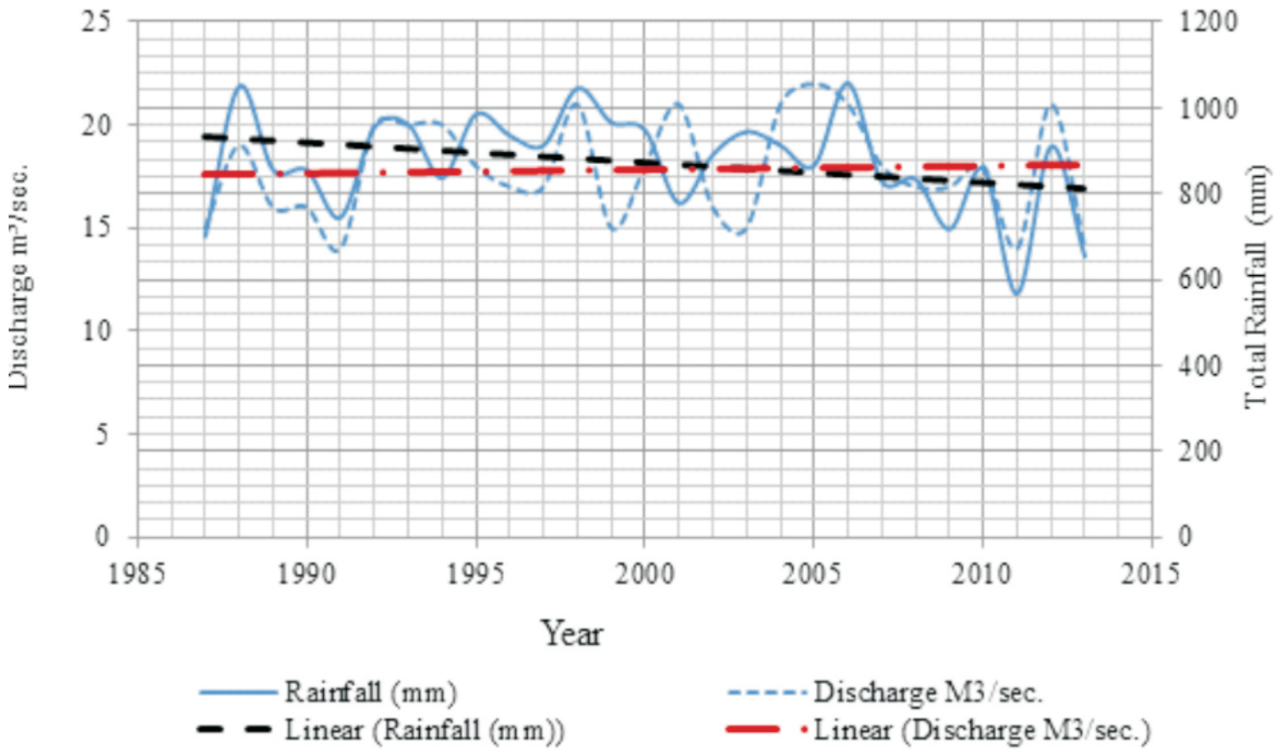

Figure. 5: Mean Annual Rainfall and Discharge Time Series for the Malabu Section of River Kilange (1987 -2013).

Source: Upper Benue River Basin Authority-UBRBA

Although the "Sahelian paradox" phenomenon is associated with increase in total volume of discharge in streams and small rivers, it is characterized by shorter duration of stream flow. As a result of the changing pattern of stream flow, most perennial rivers in the River Kilange catchment have become seasonal thereby losing their ability to provide ecosystem services.

Conclusion

Generally, the temporal distributions of annual rainfall and river discharge have become uneven from the year 2005 and the trend continued steadily at a relatively faster rate (Fig. 5). There are indications that environmental degradation have occurred in the River Kilange catchment during the period (1987-2013). The possible effects of this emerging trend should serve as a wake-up call to stakeholders in the area to formulate and implement landuse strategies that can reduce the rate of environmental degradation.

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