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An Analysis of Rainfall and Discharge Relationship at the River Kilange Catchment, Adamawa State, Nigeria

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Abstract

Rivers constitute the most important natural water reservoirs from which man derives maximum benefits for economic development. It is therefore not surprising to find most ancient civilizations in the world located around major rivers like the Euphrates, the Tigris and the Nile. This study was undertaken to find out the trends and variability of rainfall and discharge at the River Kilange catchment in Adamawa State, Nigeria. Rainfall and discharge time series data with 27 years observations (1987 to 2013) have been analyzed using the Pearson's Product Moment Correlation. It was found that mean monthly rainfall and discharge were moderately and positively correlated (r = 0.534, P=0.001). Graphical representation of the data in the study area, however, shows a decreasing trend in the annual mean rainfall, but an increasing trend in the river discharge. Improper land management may have been responsible for the strange phenomenon. It is therefore recommended that appropriate land-use management strategies be put in place to curtail further environmental degradation in the River Kilange catchment.

Keywords: Discharge, Kilange, paired samples test, Pearson's Correlation, rainfall.

1. Introduction

The global environmental change phenomenon is becoming more glaring, but there is no clear distinction between the roles played by climatic and anthropogenic factors. Most river catchments in different parts of the world experience a multitude of environmental and water resource-management problems that can be better studied at the river catchment scale. The relationship between rainfall and river discharge are so complicated, and understanding how they interact requires some local studies. This is so, because factors influencing hydrological processes on the earth surface not only vary from time to time, but also over space. As rain falls on the ground it flows through several ways to reach to stream channels, (Suleiman, 2014). 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). The portion of surface runoff, sub-surface flow, and underground flow, that eventually enters the stream channel and flows, is therein referred to as stream flow or river discharge and that is the focus of this study.

In the Sudan Savannah region of Nigeria where the River Kilange catchment is located, there are two distinct seasons in a year, the dry season and the wet or rainy season. The dry season period is characterised by seasonal water scarcity for both agricultural and domestic use for the population in the study area. Similarly, rainfall received during the wet season often occurs in extreme events, which are usually accompanied by devastating floods, soil erosion, and sedimentation of water courses. This study, therefore, investigates the changing trends in rainfall and river discharge at the River Kilange catchment with the view to understand the environmental problems associated with water resources management in the area.

` In many parts of the world, particularly the developing countries, gauging networks in river catchments are in decline as a result of the 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). The situation has made many researchers in the country abandon hydrological studies in favor of other aspects of the study (Oruonye, 2016). The difficulty encountered in generating or accessing data has made hydrological research very difficult in the country. 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.

In the River Kilange catchment, the only functional gauging station is at Malabu, a settlement located at about 45 kilometres upstream of the River Benue. Long-term stage height data for this station were accessed at the Upper Benue River basin Development Authority, Yola. River discharge data are, however, very sketchy, with only periodic records. Similarly, there is no functional meteorological station in the study catchment. This study, therefore, utilised the rainfall data which is readily available on the Internet.

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2. The Study Area

The River Kilange catchment covers an area of 4955 km^2 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’’, (Figure 1).

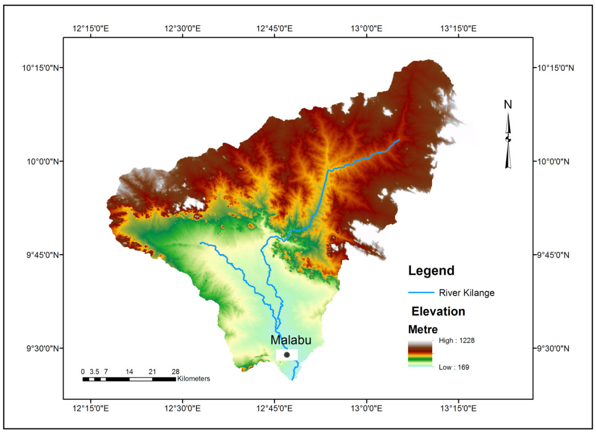

Figure 1. River Kilange Catchment Elevation and Location of the Malabu Gauging Station

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 a relatively younger age ranging from the upper Cretaceous to Quaternary periods (Bawden, 1972; Frischmann Pell and Partners-PFP-Nigeria, 1981). Elevation in the River Kilange catchment ranges from 169 Metres to 1228 metres above mean sea level as shown in Figure 1. 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 (Frischmann, Pell &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 constitute the dry season period. Mean annual rainfall in the study area is about 900 mm based on the Climate Forecast System Reanalysis-CFSR data for the years 1987 to 2013 as shown in Figure 2.

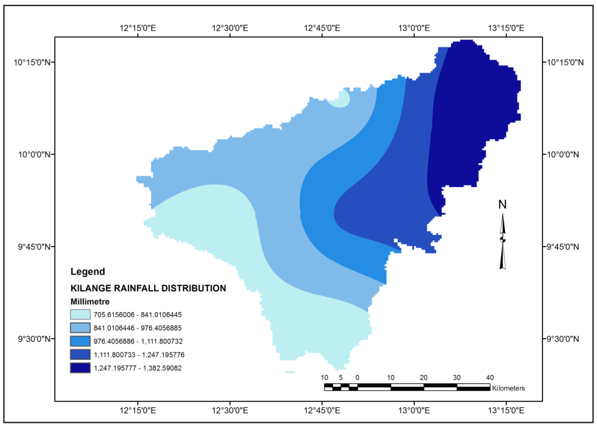

Figure 2. Rainfall Distribution in the River Kilange Catchment

Source: CFSR spell out the acronym

Temperature in the study area is characterized by little diurnal, monthly, and seasonal variations. The hottest month in the year is April, with temperatures rising to 37 °C and 39.6 °C in the northern and southern extremes of the study area respectively (Adebayo and Dayya, 2004). December and January constitute the coldest months as temperatures drop to 15.3 °C and 18.3 °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 is comprised 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 and is characterized by sparse, relatively short 5-10 metre semi-deciduous trees with shrubs and grasses constituting the dominant cover. The upland areas are characterized by shrub savannah (Frischmann Pell and Partners-PFP-Nigeria, 1981). Near the towns, the native species of trees are gradually being replaced by some exotic species. Agriculture is the major occupation 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 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, (Frischmann Pell and Partners-PFP-Nigeria, 1981).

3. Materials and Methods

There is no conventional weather station in the River Kilange catchment. This study, therefore, used the Climate Forecast System Reanalysis - CFSR daily time series rainfall data of a twenty-seven year period (1987 to 2013) available over the Internet. The monthly mean of the CFSR rainfall was calculated by summing the daily rainfall values for each month of the year and divided by the number of days in that month. Similarly, mean annual rainfall was calculated by summing the monthly mean rainfall for each year divided by the number of months. The CFSR rainfall datasets were for a twenty-seven year period (1987 to 2013). These rainfall datasets were processed in Microsoft Excel Spreadsheet to obtain the mean annual values for the twenty-seven years study period.

The other datasets used in the analysis, are: river stage, stream discharge and the conventional rainfall data which 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.

For a precise estimation of the river flow, the rating curve shall be established and verified based on hydrometric measurements conducted several times per year (Krajewski et al., 2019). Some available records on stream discharge measured through direct methods using flow metre were obtained from the Upper Benue River Basin Development Authority, Yola. Additional flow velocity and flow cross-sectional area were directly measured in the field, and the data were used to validate the historical records. The discharge values were used with recorded gauge height data to develop rating curves. A rating curve was established by simultaneously plotting the values of the water level and river discharge in Microsoft Excel Spreadsheet. This follows the method of Tarpanelli et al. (2013), who suggest that a curve be fitted through the measured hydraulic variables. After plotting the stage versus discharge, a smooth curve was drawn through the plotted points (Figure 3).

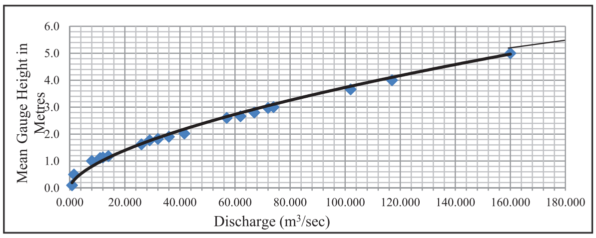

Figure 3. Stage-Discharge Rating Curve for the River Kilange at Malabu

By using the prediction curve, one can simply take the gauge reading and estimate the river discharge (Gnacadja, 2013). The water level records are shown on the 'y' axis, while discharge is on the 'x' axis, and the relationship curve is used to determine the discharge for any given value of water level.

4. Results and Discussion

The mean annual discharge and rainfall time series were analyzed to better understand their relationships and to evaluate the consistency of the data used. 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. The web-based weather data can be used for analyses, particularly in data-scarce river catchments (Dile and Srinivasan, 2014; Fuka et al., 2013). The CFSR rainfall data for Malabu weather station was used to analyze rainfall-discharge relationship in this study.

Analysis of mean monthly rainfall and discharge at the Malabu section of River Kilange revealed that rainfall is the primary determinant of river discharge in the study area. Although the river is characteristically perennial, the highest values of both rainfall and discharge occur in the months of August and September respectively as shown in Figure 4. The 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 as shown in Figure 4. The dry season discharge is attributed to underground seepage.

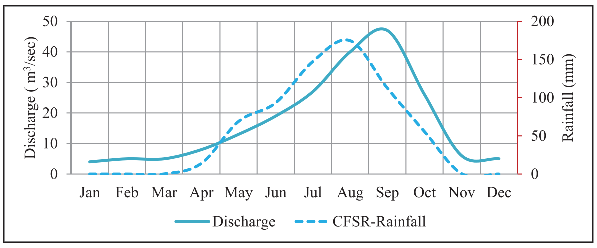

Figure 4. Annual Trend of Rainfall and Discharge at River Kilange Catchment (1987-2013).

The observed seasonal variation in both rainfall and discharge can serve as important information for water resource planning and environmental management in the study area. Annual water scarcity can be predictable since there are distinct dry season months (January to March and November to December). Efforts can, therefore, be made to provide mitigation measures that can reduce the negative impacts of the seasonal water shortages that affect both domestic and agricultural undertakings. Similarly, extreme weather events such as flooding and erosion, which occur in the months of August and September very often, can be predicted based on the depth of rainfall observed. Proactive measures can, therefore, be put in place to reduce the consequences of erosion and flooding that occur at the peak of the rainy season.

Pearson's Product Moment Correlation was used to analyze the relationship between mean annual rainfall and discharge at the River Kilange catchment. The 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). The result of the correlation analysis was moderate and positive (r = 0.534 P = 0.004). The correlation is also significant since the P-value (0.004) is less than (0.05). 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 negligible or non-existent. Since the correlation analysis between rainfall and discharge, does not exhibit perfect relationship, it can be discerned that other underlying factors apart from rainfall play significant roles in influencing river discharge in the River Kilange catchment. Krajewski et al. (2019) made similar observations, when they affirm that, the distinction between the exact factor driving changes in water resources (land use or climate change), which occur simultaneously in watersheds, are not possible to distinguish with the few variables analyzed. Although it is outside the scope of this study to examine these factors, anthropogenic activities, particularly landuse changes, can partly account for the increase in the river discharge. Therefore, this study suggests that additional causative variables be investigated in the subsequent studies.

Graphical representation of mean annual rainfall and discharge at the River Kilange catchment revealed that there is a steady increase in river discharge during the study period (1987 to 2013) as shown in Figure 5.

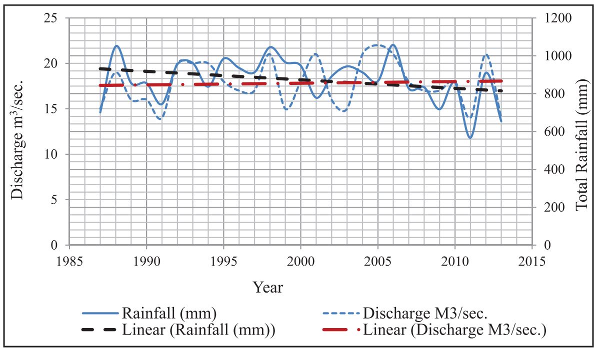

Figure 5. Time Series on Rainfall and Discharge at River Kilange (1987 -2013).

Source: Upper Benue River Basin Authority-UBRBDA, 2018.

The time series of long-term data (1987-2013) have shown that the distributions of rainfall and river discharge have become uneven from the year 2005. The disparity continued steadily to the end of the study period. This finding reveals that a strange environmental phenomenon has started to manifest itself in the Sudan Savanna zone of Nigeria. This strange environmental phenomenon is called the 'Sahelian paradox' because, it was first observed in the Sahel Savannah ecological zone of West Africa, (Amogu et al., 2010). The "Sahelian paradox" is an environmental phenomenon characterized by a steady increase in stream flow without commensurate increase in rainfall. Although the "Sahelian paradox" phenomenon is associated with increase in the total volume of discharge in streams and small rivers, it is characterized by a shorter duration of stream flow (Amogu et al., 2010).

5. Conclusions

The two basic data used in this study are the Climate Forecast System Reanalysis-CFSR rainfall and river discharge estimated from gauge height (water level) records at the Malabu section of the River Kilange. These datasets were used for meteorological and hydrological analyses in the data-scarce River Kilange catchment. The findings of this study indicate that there is close affinity between rainfall and discharge in the River Kilange catchment. Analyses of the long-term data (1987-2013) revealed that rainfall is the primary determinant of discharge in the study catchment. It was however observed that, while the mean annual rainfall showed downward trend, an upward trend was observed in the mean annual discharge over the study period. The changing patterns in rainfall and river discharge can be an indication that water resources are decreasing in the River Kilange catchment. The observed increase in river discharge without commensurate increase in rainfall implies that the catchment loses considerable proportion of rainfall that would have percolated into the ground.

There is thus, the need to provide mitigation measures to reduce the quantity of water lost through excessive stream flow in the study catchment. The impacts of disastrous environmental phenomena such as erosion and flooding can as well be controlled through certain landuse strategies. Earth dams can be constructed to impound excess water during the high flow periods to be used when water is scarce in the dry season. Embankments can also be constructed at appropriate locations to reduce the rate of erosion and flooding during extreme rainfall events. These steps and similar landuse strategies, when put in place, can help considerably in sustaining the environmental resources in the area.

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