PROBLEMS OF LOWER BENUE RIVER BASIN AND SUSTAINABLE DEVELOPMENT UNDER INCREASED EFFECTS OF CLIMATE CHANGE IN NIGERIA

Abubakar, Mahmud[1*] and Yusuf Muhammad Adamu[2]

[1*]Department of Geography, Nasarawa State University Keffi, Nigeria.
[2]Department of Geography, Bayero University Kano, Nigeria.

***Corresponding Author's e-mail:drdanbarau@yahoo.com**

Abstract

Problems of ecological disaster whether natural or man-induced have been on the increase in Nigeria exacerbated by Climate Change may pose major threat to the Nigerian economy by the year 2020. The objective of this study is to collect, explain and analyze some Hydrometeorological data using conventional statistical methods and derived parameters. The results revealed that annual rainfall curve for Makurdi indicates two periods of increased rainfall and followed by two periods of marked decrease lasting till 2005. In between these periods, the patterns of rainfall are oscillatory. Mean annual areal volume of Actual evapotranspiration is 23, 262.4 x 10^6 m^3. Soil moisture deficit is from December to April in Wase basin. The mean annual soil moisture deficit is 312mm, with the annual areal volume of 20, 295.2 x 10^6 m^3. Of the crops grown in the three sub-catchment basins, those in southern portion of Katsina-Ala and Wase River Basins are likely to perform better on rain fed agriculture. Organized urbanization has compounded the problems of flooding and erosion in the Lower Benue River Basin – this problem has greatly altered the soil cover from one of woodland savannah in the rural environment to that of open surfaces, build-up slopes and valleys and general over-exposure of the city center to greater surface flow. The study recommends application of rainfall effectiveness indices and hydrological parameters in various problem areas of the Lower Benue River Basin.

Keyword: Lower Benue River Basin, Climatic variability, Water balance, agricultural planning, flood and erosion.

INTRODUCTION

Problems of ecological disaster whether natural or man-induced have been on the increase in Nigeria. The Federal Government estimation is that more than 850,000 hectares of land is lost to flood and erosion yearly. Statistics indicate that 0.5 percent of the country's 923,768 square kilometers landmass has been degraded by gully erosion. This amounts to about 4,619 square kilometers or an area bigger than Lagos State. More than 30 million tones of soil is lost yearly to erosion and flood (Adefolalu, 1988; Adefolalu, 1996; Umoh, 1999).

Nigeria has abundant freshwater resources – both the availability of fresh water for domestic, agricultural and industrial consumption especially Hydro-Electric Power Generation. But there are problems. The timing and intensity of rainfall is a major determinant of runoff, flooding, groundwater recharge and also soil erosion. Flooding can lead to siltation and contamination of water with human, soil, animal waste, and agricultural chemicals. Reduced water level can concentrate pollutants during drought. Such problems will be exacerbated by Climate Change may pose major threat to the Nigerian economies in the world by the year 2020.

This study is premise on the fact that the real problem has to do more with sustaining the Renewable (Water and Irrigation) Resources. Preliminary work carried out on the fundamental causes of low output from the Lower Benue River Basin indicate the following as major *problems* to be tackled.

a) Erosion-induced Sedimentation resulting in silting-up leading to false water depth, and highly turbid water;

b) High rates of evaporation from the 'standing' Dam with non-stationary tendencies, especially due to droughts;
c) Poorly Programmed water discharge in relation to rainfall seasonality.

Flood and erosion occur widely in the Savanna Belt of the Lower Benue River Basin. The major casualties of flood and erosion have been homes, whole communities, farmlands, roads, bridges, public buildings, and industrial installations. Many lives have similarly been lost. Losses to flood and erosion in Nigeria have been great and unquantifiable. The Federal Government, public and private agencies as well as different state governments in recent years have spent millions of Naira in the area of landscape reclamation.

In the states within the Lower Benue River Basin (Plateau, Nasarawa, Benue, and Kogi States) there have been problems of water shortage and pollution, land wasting, and declining agricultural productivity (Ayaode 2002; Adams, 2012). Government instead of addressing the root causes of the problem and finding solutions resorted to ceremonial tree planting exercise, grain and fertilizer importation and distribution to every Local Government Area. Past governments in their effort established different agricultural programmes as Operation Feed the Nation (OFN) 1975-1979, Green Revolution Programme (GRP) 1979-83, Accelerated Food Production Experiment 1983-86 as well as introduce various slogans in the realm of agricultural production. All these have failed to achieve the expected goal.

It is now feared that damming of the Lower Benue River Basin and some of its tributaries have created problems in the catchment areas. The immediate discharges consequences of this project include low stream flow discharge downstream and siltation of the rivers (Ayaode, 2004; Chukwu, 2004; Adams, 2012). Some of the rivers have dried up to the role of human interference and desertification trends. Some major tributary rivers as Wase, Mada, Dep, Katsina-Ala and Okulu are sub-perennial in discharge consequently; the rivers break up into standing ponds during the dry season particularly in November and April. The sub-perennial behavior of these rivers is related to the geology of their channels and the size of their catchment areas (Chukwu, 1999, 2002; Baba, 2007). Consequently, in most locations within the river basin, water becomes a major problem for animals, crops and humans.

Materials and Methods

Figure 1 is the Lower Benue River Basin is located on latitudes 6^0 35^l 00"N – 10^0 30^l 00"N and longitudes 6^0 35^l 00"E – 10^0 20^l 00"E. It covered an area of 146,9000 sq. Km includes the lower reaches of the Benue valley stretching confluence of the Benue and Niger rivers to the south. The lower Benue river basin encompasses the middle Benue and only the northern ringes of the "lower Benue" geological areas (Offodile, 1991). The operations of the Lower Benue River Basin Development Authority cover the whole of Benue, Nasarawa, Plateau States as well as part of Kogi State East of the River Niger. (LBRB Public Relations Unit, 2000). The river basin is divided into three major sub-catchment basins namely: Wase sub-catchment; Mada sub-cathment; Katsina-ala sub-catchment (Figure 1).

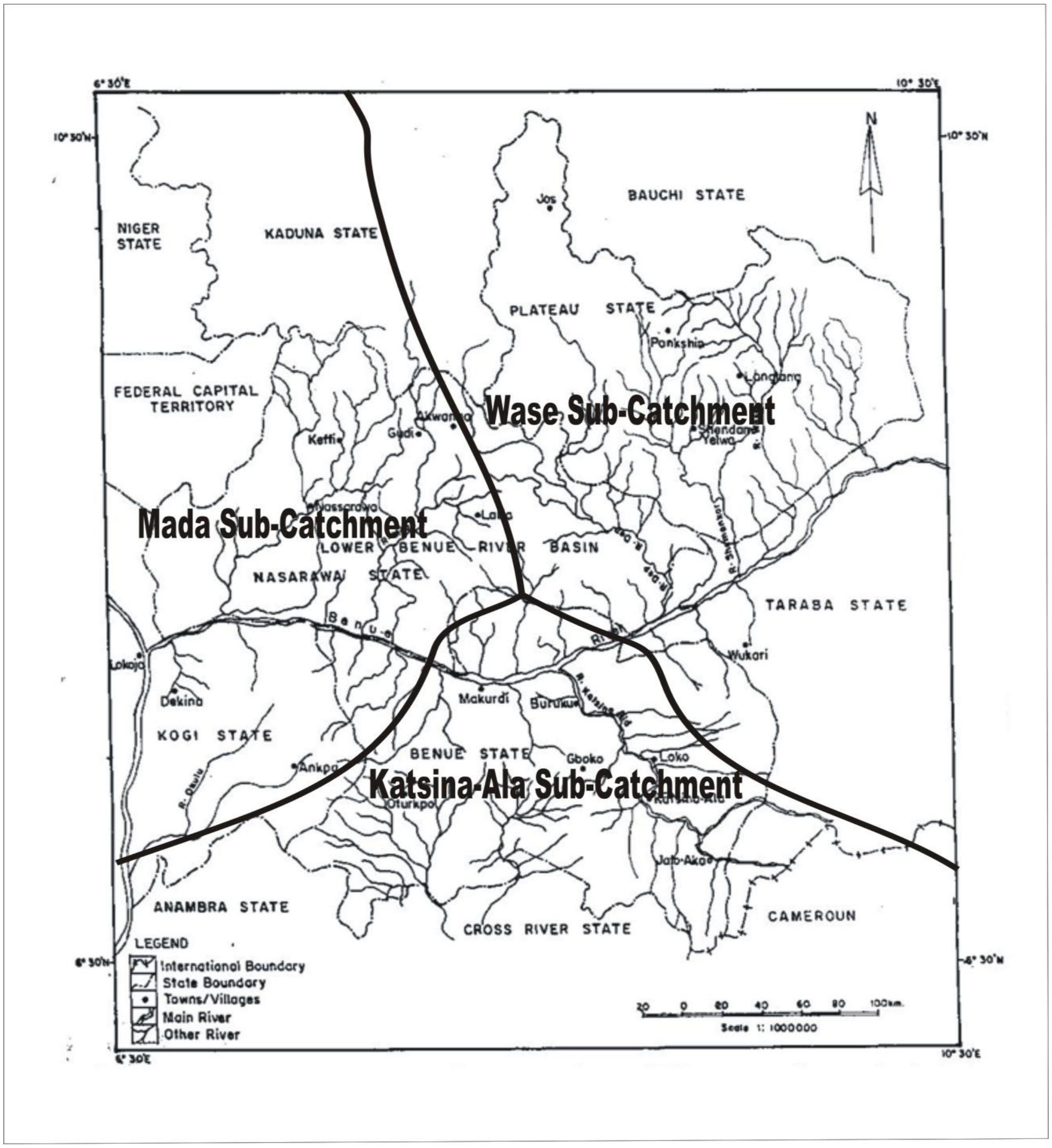


Figure 1: Lower Benue River Basin

Data on environmental problems in the Lower Benue River Basin were collected and analyzed using a comprehensive use of computer software package SPSS version 17 that:

i. Test of variability using standard deviation (S) and coefficient of variability (CV).
ii. Construction of standardized score (Z-score) using Gaussian low pass filter technique for detecting marked fluctuations.
iii. Test for normality using coefficient of Skewness (SK).
iv. Regression model for examining the degree of relationship between monthly

rainfall and monthly water levels and,

v. Time series analysis.

vi. Water balance model given as:

$W/F = D_{wet} [RR_{wet} - Q_{wet}] + D_{dry} [RR_{dry} - Q_{dry}]$

Where; W/F is the water balance per unit heat (specific heat)

D_{wet} is the number of days in wet season

RR_{wet} is the amount of rain received in wet season

Q_{wet} is the quantity of heat lost during wet season

D_{dry} is the number of days in dry season

RR_{dry} is the amount of rain received in dry season

Q_{dry} is the quantity of heat lost during dry season

vii. Runoff processes

The NRCS TR-55 method for estimating peak runoff using the results from numerous small and mid-sized basins for homogeneous catchments in which curve numbers greater that 50 were used; and described as:

$$Q_p = q_u A P_e F_p$$

Where: Q_p is in m^3/s;

q_u is the unit peak discharge in m^3/s per cm of runoff per km^2 of area;

A is in km^2; P_e is the 24-hour rainfall excess in cm for a given return period;

and F_p is a dimensionless adjustment factor to account for ponds and swamps that are not in the primary flow path.

viii. Computation of potential evapotranspiration, other hydrological parameters, irrigation requirements of crops and Precipitation effectiveness parameters.

The onset, cessation (end) and duration of the rainy/growing season were computed using Walter's (1967) formulation because of its higher reliability in predicting the onset/ end of the rains among different methods. The method is expressed as:

$$\text{Onset/end dates/days} = \frac{DM(51-A)}{TM}$$

Where, DM, is the numbers of days of the month containing the date of the onset and end,
A, is the accumulated total rainfall of the previous months.
TM, is the total rainfall for the month in which 51 mm or more is reached; and 51 mm, is the threshold of rainfall for both the onset and the end months.
Duration of the rainy season is the differences between seasons were computed by subtracting the end and onset of the rainy season.

Annual rainfall totals were derived from the summation of monthly rainfall for each of the 20 years. Because potential evapotransp-iration data were not available from all the stations, Penman's (1948) formula has been used to derive estimates of evapotranspiration. Similarly, actual evapotranspiration estimates were derived according to the method of Ayoade (1971). The consumptive uses of water by the selected crops were calculated using the method of Porter (1976). He defined the consumptive use of water by crops as:

$$U = Et/E0 \times E0 \text{------------(2)}$$

Where, U, is the consumptive use of water,

Et/E0; the crop coefficient,

and where Et is the actual evapotranspiration from crop surface determine by lysimeter studies,

and E0= open water evaporation. In this study, the method of Wolfgang (1981) based on actual water availability-potential evapotranspiration relation were used to determined the duration of effective water availability of different grades in the basin area.

This humidity assessment ratio is expressed as:

$$\frac{\text{Actual water availability}}{\text{Potential water needs}} = \frac{AWA}{PE} \text{.... (3)}$$

Where, AWA = actual evapotranspiration for moist when precipitation (P) is less than potential regional evapotranspiration (PE), that is if P<PE, AWA = AE

To be able to formulate humidity reference numbers and establish the humidity zones in the basin area, the computed AWA/PE ratio were used to defined humidity number. Each of the humidity number represents the duration of periods of water availability of different grades.

Fluctuation graphs of study variables were achieved by plotting the values of each of the variables over the period under consideration (1986-2005). The fluctuations were filtered using 5-year moving averages to smoothen the high frequency fluctuations into periods of decrease or increase in the study variables.

ix. Precipitation effectiveness parameters.

The effective rainfall *U* is computed from the observed rainfall *P* and the moisture deficit from the drainage equation

$$dU/dP = 1 - D/a \qquad D \le a$$

$$dU/dP = 0 \qquad D > a$$

Where *a* is a threshold parameter for generation of effective rainfall.

Finally the moisture deficit is updated using the mass balance equation $dD/dt = E + U - P$. the four parameters of the moisture module deficit, are optimized against measured stream flow records.

Results and Discussion

Climatic Variability

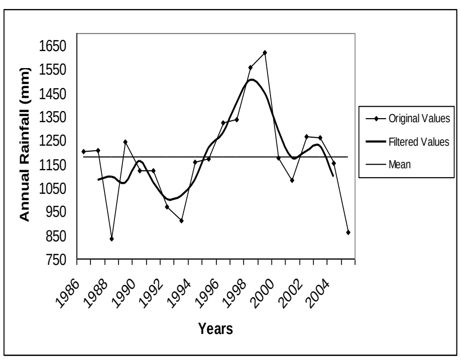
Climatic variability includes the extremes of rainfall (i.e. drought and floods) and differences of monthly, seasonal and annual values from normals. In order to show the possible long-term fluctuation in rainfall over the Lower Benue River Basin, yearly rainfall values for some years were plotted for selected stations of which are illustrated in Figure 2. The rainfall regimes for these stations are generally in the form of alternating wet and dry epochs. The annual rainfall curve for Makurdi indicates two periods of increased rainfall: 1989-1991; 1994-2003; and followed by two periods of marked decrease: 1992-1993; followed by a period of decrease, lasting till 2005. In the Lokoja Area, the period of increased rainfall are 1988-1989 and 1991-2004 and marked decrease were observed for 1990; 1992-1993; 2005. In the Jos area, two periods of increased rainfall were 1986-1998 and 2005, and two period of marked decrease: 1992-1995; 1996. In between these periods, the patterns of rainfall are oscillatory. The time series of other stations are of the same pattern as describe above.

Descriptive statistics for annual rainfall series in the Lower Benue River Basin for the period are shown in Table 1. Generally the temporal pattern has fluctuated with a tendency to decline. During the period, Lokoja registered the highest mean annual rainfall of 1261 mm while Yelwa had the least being 1062 mm. The standard deviation ranged between 159.2 for Yelwa and 291.0 for Lokoja. It can also be seen from Table 1that annual variability in rainfall over Lower Benue River Basin differs from station to station. The Coefficient of Variation lies between 10.8 percent at Makurdi and 21.2 percent at Jos. Even though the annual variability for all the stations is relatively low, the year to year variability is lowest in Makurdi and highest in Jos. Other stations fall in between these extreme values.

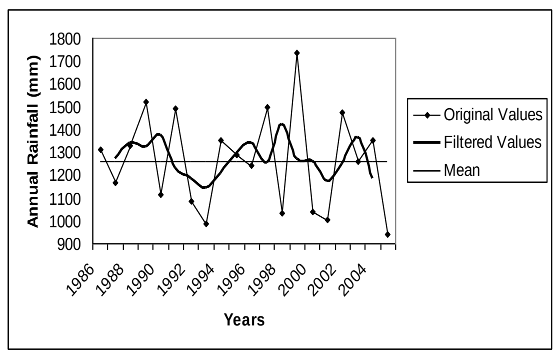
The distribution for the stations is significantly and positively skewed. This means that the bulk of the values are less than the mean. Jos has highest skewness of 1.71 while Lokoja has the least, 0.31.

Computation of basic statistical parameters of Jos, and Lafia revealed that the mean annual rainfall of Jos over the period is 1219 mm with standard deviation (SD) of 287.1 mm. Of this total 1152 mm or 92.5% (with a SD of 219.8 mm) fell in the months of May to October. Mean annual rainfall and rainy season coefficient of variation (CV) were 21.2 and 17.4%, respectively. For Lafia and Yelwa, the annual rainfall was 1234 mm and 1062 mm, respectively, with annual Coefficient of Variation of 18.1 percent for Lafia and 14.1 percent for Yelwa. The percentage for mean annual rainfall and rainy season Coefficient of Variations ranged between 18.1 – 21.2%.

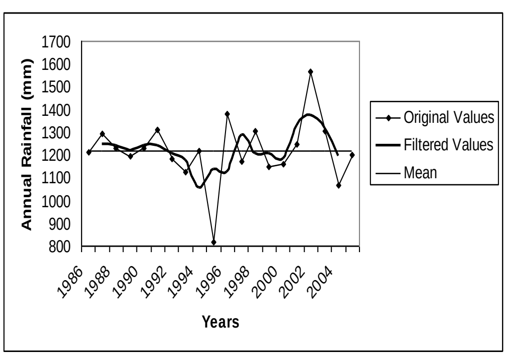
(a) MAKURDI



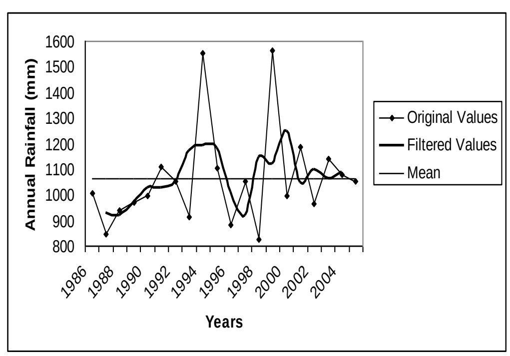
(b) LOKOJA



(c) JOS



(d) YELWA



(e) LAFIA

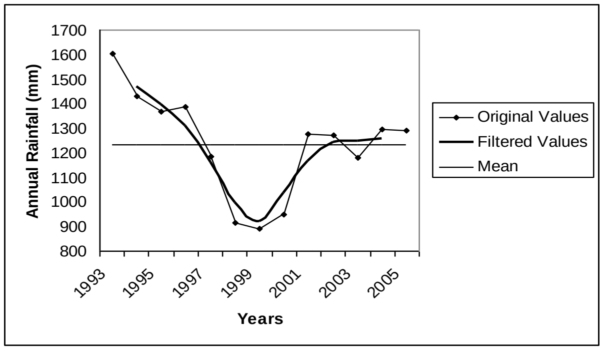


Figure 2: Annual rainfall series over Lower Benue River Basin (1986-2004).

Table 1: Statistical Properties of Annual Rainfall at five stations in the Lower Benue River Basin

Station	Mean	Standard Deviation	Coefficient of Variation	Skewness
Makurdi	1194	163.6	10.8	0.41
Lokoja	1261	291.0	20.3	0.31
Jos	1219	287.1	21.2	1.71
Yelwa	1062	159.2	14.1	0.52
Lafia	1234	202.9	18.1	0.40

Water-Balance Parameters

The result of hydrological parameters of Wase sub-catchment basin with an extent of 42, 999Km^2 show that: annual volume of rainfall is 20, 877.7 x 10^6 m^3 while volume of surface runoff is 5, 545.8 x 10^6 m^3. The mean annual infiltration is 426mm while the annual volume of 27, 777.4 x 10^6 m^3. Mean annual volume of Actual evapotranspiration is 23, 262.4 x 10^6 m^3. Soil moisture deficit is from December to April in Wase basin. The mean annual soil moisture deficit is 312mm, with the annual volume of 20, 295.2 x 10^6 m^3. The areal extent of Mada catchment is 6786 square kilometers and the computed annual area volume of the water balance parameters show that:

(a) Rainfall is 8720.0 x 10^6 m^3
(b) Infiltration is 4390.5 x 10^6 m^3
(c) Actual evapotranspiration is 4492.3 x 10^6 m^3
(d) Soil moisture deficit is 2660.0 x 10^6 m^3
(e) Surface runoff is 1031.5 x 10^6 m^3

These figures were calculated with the aid of ArcGIS 3.9 released.

The Katsina-Ala River catchment basin has an area extent of 21,357 km^2, while annual areal volumes of calculated water balance parameters for:

(a) Rainfall is 33,863.6 x 10^6 m^3
(b) Infiltration is 17,607.6 x 10^6 m^3
(c) Actual evapotranspiration is 16,705.9 x 10^6 m^3
(d) Soil moisture deficit is 8,281.7 x 10^6 m^3
(e) Surface runoff is 4,840.9 x 10^6 m^3

Table 2: Annual Averages of Water Balance of the Niger River Basin

Measurement (mm)	Wase	Mada	Katsina-Ala	Mean
Rainfall	1,253	1,285	1,427	1,321.7
P.E.T.	1,112	1,053	1,053	1,072.6
R.A.S.	150	180	180	170.0
Infiltration	646	647	742	678.3
A.E.T.	541	662	704	635.6
S.M.D.	472	392	349	404.3
Surface Runoff	129	152	204	161.3

The results of the set of water balance calculations for the three sub-catchment basins are presented in Figure 3 which summarizes information on the average hydrology of the three sub-catchment basins of the Lower River Niger Basin. The figures show the seasonal patterns of rainfall, evapotranspiration and surface runoff. It indicates times of moisture deficit, recharge and surplus.

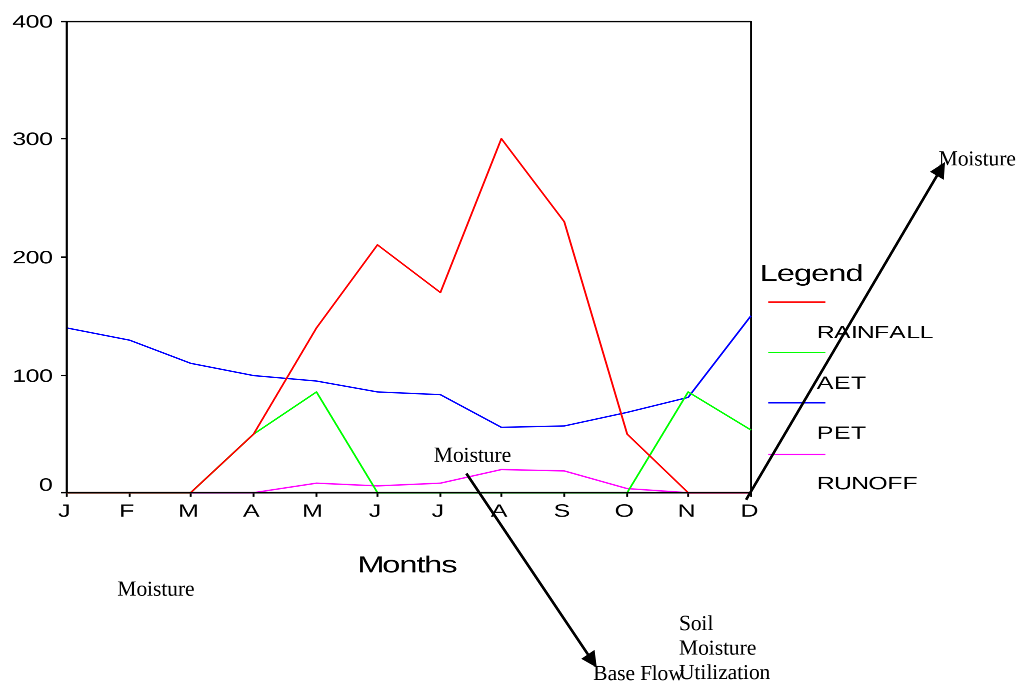


Figure 3: Average Monthly Water Balance of the Lower Benue River Basin

A comparison between rainfall and actual evapotranspiration (AET) is illustrated in Figure 4 for Lower Benue River Basin. Table 2 summarizes the annual averages of water balance components of the Lower Benue River Basin.

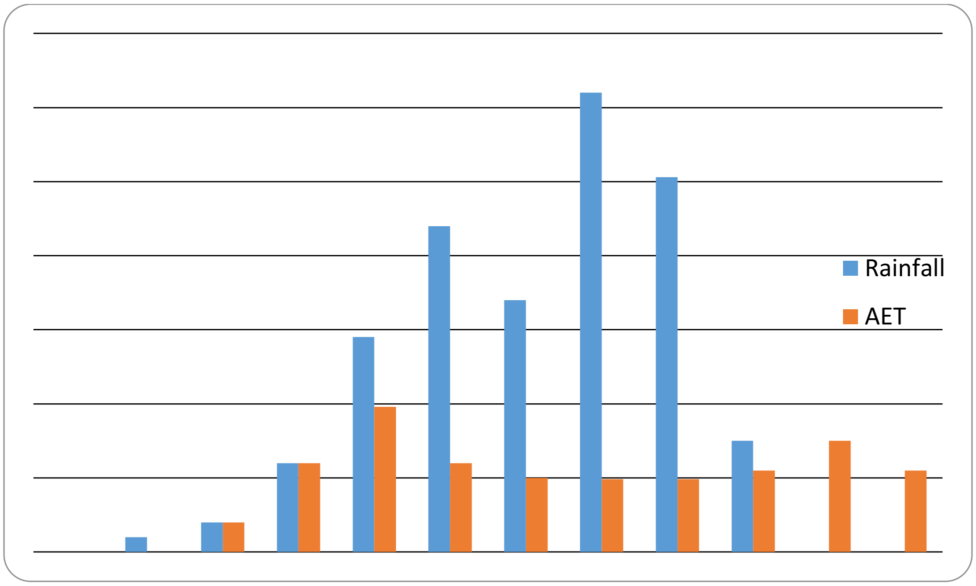


Figure 4: Average Monthly Mean Rainfall and Actual Evapotranspration (1970-2010) for Lower Benue River Basin.

The mean annual areal rainfall of the catchment basin is 1321.7 mm. Potential Evapotranspiration (PET) is 1072.6 mm while actual evapotranspiration is 635.6 mm. The soil moisture capacity (RAS) is 170 mm on the basis of 1.0mm effective root zone, while infiltration or recharge to groundwater is 678.3 mm. Soil Moisture Deficiency (SMD) and surface runoff are 404.3 mm and 161 mm, respectively.

Domestic Water Needs and Supplies

Adequate supply of water for drinking, personal hygiene and domestic purposes is essential to public health and well being. Total domestic water needs in homes with amenities and inside sanitation is at least 115 litres per person per day (Abubakar and Sani, 2012). Apart from climate, total water demand depends upon the population and the level of development as reflected by the water-consuming productive activities. But very regrettably, within the study area, water shortages are rampant in urban centers particular particularly during the dry season when many of water sources (spring, streams, pond, hand-dug well and taps) dry up. People are obliged to trek long distances in search of water.

Water yield is influenced by the geological units of the area. In the Lower Benue River Basin, these units are the basement complex and sedimentary basin. In the basement complex area, where the aquifers are limited and in isolated compartments, the surface water resources have the problem of low base flow of rivers. The base flow of rivers is usually low because of the low bedrock storage. The storage does not sustain river flow during the dry season; even large river, that break-up into deep standing ponds during the dry season. Virtually all smaller rivers dry up altogether during this period. Thus there is acute water shortage during the dry season in most parts of the Lower Benue River Basin.

Water schemes which serve Keffi, Akwanga, Doma, Lafia, Ajaokuta, Makurdi, and other towns were meant for domestic uses. Other water projects such as weirs, dug wells and perennial, and bore holes in most rural communities have been provided by the government. Domestic water consumption takes on seasonal pattern, with heavy demand in the dry season, when more water is required. In the rainy season, consumption is slightly reduced. In some urban areas of Nasarawa State such as Keffi and Akwanga, it is estimated to be about 50 litres per day per person while in the rural areas; it might be as low as 35 litres per day per person. In the dry season, the requirement in the urban areas might rise to about 70 litres per day per person. Presently, the daily water requirement at all seasons of Lafia is 40,250 m^3/day. Keffi town daily supply is about 2,000m^3/day while the water demand is 31,600m^3/day. In Makurdi the supply of treated water is 96,300 m^3/day whereas water need is the 420,000 m^3/day. This situation is the same in all the urban centers within the river basin. The supply is far less and cannot meet the enormous demand in these urban and sub-urban centers of the study area (Abubakar, 2013; Chukwu, 1999; 2000; 2002).

Agricultural Planning

Onset, cessation and length of rainy season (LRS) are useful parameters for agricultural planning for improved yields. The onset of rains in the Lower Benue River Basin is between April 17 and May 25. The agricultural implications are that if the same type of crop is raised in the three sub-catchment basins, assuming that the soil types are similar, those in southern portion of Katsina-Ala and Wase River Basins are likely to perform better on rainfed agriculture. Moreover, because of earlier onset, there is a likelihood of faster development and early maturity of the same plant species. It should be noted that in no part of the study area should planting of seasonal crops, grains be started before April 17 for rain fed agriculture.

The cessation date of rains within the study area is between September 29 and October 25. A unique feature of the cessation dates is the shorter interval of less than 15 days required for termination of the rains regardless of the type of season – be it one of premature, normal or delayed cessation. In the Lower Benue River Basin, the end of rains is sharp and decisive and this useful in agricultural planning for suitable crops. A crop that cannot reach maturity before the respective cessation dates in any of the sub-catchment basin will result in lower yield except where supplementary irrigation can be carried out.

Flood and Erosion

Flooding and erosion are usually associated with surface runoff in general and heavy or intense rainfall in particular. In the Lower Benue River Basin, organized urbanization has compounded this problem. This has greatly altered the soil cover from one of woodland savannah in the rural environment to that of open surfaces, build-up slopes and valleys and general over-exposure of the city center to greater surface flow without adequate provision of drainage channels.

Vegetation is stripped off in many places and the soil is compacted by modern machineries or turned into concrete top cover. The roofing patterns are those that encourage rapid runoff from housetops into the paved surfaces. Since the infiltration capacity of the soil is a function of how porous the topsoil is, the rate of percolation is reduced and more surface flow is encouraged. In the Lower Benue River Basin therefore, the sloping landscapes suffer from erosion and wash-off (of topsoils) while the bottom terrains are perennially flooded.

Four types of flood have been identified in the Lower Benue River Basin based on causes, characteristics and consequences. They are flood plains flooding, localized flooding, flash flooding and general flooding. Flood plain flooding occurs when excessive discharge cannot be contained within the confines of river channel particularly between the months of July and September. Most areas affected are Toto, Ankpa, Gboko and Dekina. Localized inundations due to tidal effects are experienced in the low-lying riverine areas. The floods are of short duration and are generally of moderate depth. The affected areas are Doma, Katsina-Ala, Bukuru, Toto and Kokona.

Hydrological events in the Lower Benue River Basin are few. These include the 2012 flood disaster in Lokoja, Toto, Kokona and Makurdi. The causes of this flood range from high rainfall, poor road drainage (culverts), many people living around these areas were rendered homeless, farmlands and cattle were also destroyed.

Soil erosion and gullying are due to natural surface flow of water and terrain effects. Soil erosion due to excess surface flow is dominant in areas with deep gradient as observed in Lafia, Kukari, Shendam Yelwa and Oturkpo. The more continuous and more lateral washing off of topsoils due to sheet flow is dominant feature in all towns and villages within the study area lasting rainfall types.

The construction of dam to provide irrigation water, flood control, power, fisheries or transport has many consequences including those of social and economic nature. Dam construction results in loss of land through inundation and implications for water table levels. Silting behind dam reduces downstream sediment load. Loss of sediments in reservoirs has downstream implications. Vegetation, agriculture and fisheries may not have been adapted to periodic flooding before dam construction but also to the deposition of sediments including important nutrients. Trapping of silts by lake for example results in impoverishment of alluvial floodplain. Remedies do not exist for such effects, for example, fertilizer use, but this involves economic and social considerations. Dam construction reduces peak flow and increases low flows. It causes floodplain contraction and alters channel geometry. Socio-economic impacts include migration of entire villages which were inundated, fishing industry losses and deterioration of summer resorts.

On flood abatement and measures to curb erosion, drainage systems need be improved. Planting of grasses to check surface flow, especially in the area of steep slope should be introduced. Terracing is suggested in areas of steep slopes with grass planted on each contoured terrace to curb excessive washing off topsoil.

Conclusion

Lower Benue River Basin, like many parts of the tropical worlds has experienced pronounced climatic variations with their accompanying climatic events and environmental problems. The disastrous decline in rainfall is reflected in low discharge. Environmental problems such as flood and erosion are climate-induced. The availability of water for domestic and industrial purposes also obviously reflects rainfall. Many rivers suffer much loss of water through evapotranspiration and infiltration. These have serious implication in agriculture, water supply, flood, erosion, sanitation, transportation and hydroelectric power generation among others. The solution is an understanding and application of rainfall effectiveness indices and hydrological parameters in various problem areas.

REFERENCE

Abubakar, M. & Sani H. M. (2013). 'An Assessment of Financial Efficiency and Economic Viability of Water Supply in Nasarawa State – Nigeria. NSUK Journal of Science and Technology. In Press.

Adams, W. M. (2012). 'Large Scale Irrigation in Northern Nigeria: Performance and Ideology'. Transact Inst. Br. George. NS 16:287 – 300.

Adefolalu, D. O. (1986). 'Rainfall trends (1911-80) in relation to water-use problem in Nigeria'. Theo. Appl. Climatol. 37: 205-217.

Adefolalu, D. O. (1988). 'Precipitation, evapotranspiration and the ecological zones of Nigeria'. Theor. And Appl. Climatol. Series. 39: 81-89.

Adefolalu, D. O. (1996). 'Analysis of precipitation intensities for flood/erosion control in Nigeria'. Univ. FUT-Minna Res Re R-46. 7 pp. + Figs.

Ayoade, J. O. (1971) "Rainfall, Evapotranspiration and the Water Balance in Nigeria ".Unpublished Ph.D, University of London.

Ayoade, J. O. (2002). Introduction to Agro-Climatology. Ibadan: Vantage Publishers.

Ayoade, J. O. (2004). *Introduction to Climatology for the Tropics* 2nd edition, Ibadan: Spectrum Books Limited.

Baba, J. M. (2007). 'The Impact of Large – Scale Irrigation Projects in Nigerian Northern Savanna Belt. In A. O. Sand (Ed.), Comparative Strategy for Agricultural and Rural Programme in Nigeria. Chapter 27.

Chukwu, G. O (2004). Consumptive use of water by root crops in Nigeria. In: Contemporary Issues on food and fiber production in Nigeria.

Chukwu, G. O (1999). Estimation of Water requirement of soyabeans and groundnut in Southeastern Nigeria, Journal of Sustain. Agriculture and Environment. 1(1).

Chukwu G. O. & Eze, P. C. (2002). Comparing Blaney-Criddle and evaporimeter methods of estimating evapotranspiration of soyabeans. Proc. 36th Ann. Conf. Agric. Soc. Of Nigeria FUT, Owerri.

Chukwu, G. O. & Ikwede, G. (2000). Irrigation water management studies". At National Root Crop Research Institute, Umudike: An update proc. Food and fibre in Nigeria. In the 21st century. College of Agric and Medicine, ABSU, Umuahia.

Chukwu, G. O. & Mbanso, P. (1999). Crop water requirement of radish in South eastern Nigeria. Journal of Sustain. Agric. And Environ. (2).

Goodland, R and Ledec, G. (1987). 'Economics and Principles of Sustainable Development'. Ecological Modeling. Vol. 38.

Ledger, D. C. (1987). 'Some hydrological characteristics of West African Rivers'. Transaction of the Institute of British Geographers, 35, 73-90.

Mmimokou, M. & Rao, A. R. (1983). 'Regional monthly rainfall-runoff model' Journal of Water Resources Planning and Mangement. 109, 75-93.

Offodile, M. E. (1991). '*An approach to ground water study and development in Nigeria'. A geography of Nigeria Development.* 2nd ed. London: Heinmann Education Books.

Penman, H.L (1948) Natural Evaporation from open water, bare ground, and grass surface. R.Soc. Ser. A. 193.

Porter, P. W. (1976) Climate and Agriculture in East Africa. In: C.h. Knight and J.L. Newman(ed) Contemporary Africa, New Jersy.

Umoh. U. T. (1999). 'Climatic variability and rainfall-straemflow relationships in parts of Niger River Basin of Nigeria'. African Climatological Research Series. Vol. 3, 10-22

UNDP (1991). Human Development Report. Oxford University Press. NY. Walter's, M.W (1967): The Length of the rainy season in Nigeria. Nigerian Geographical Journal, 10.

Wolfgang, S. (1981). Humidity and cultivated plant-an attempt at parallelizing zones of humidity and optimal location of selected cultivated plants in the tropics. Appl. Geor. Development. 17