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IMPACT OF DAMS ON HYDROLOGY OF RIVER NIGER AT LOKOJA, NIGERIA

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Abstract

River Niger traverses two humid catchment areas that are separated by a wide expanse of semi-arid environment. Within its lower course, the river has been impounded at two points (Kainji and Jebba) for the sole purpose of generating electricity. This paper discusses the hydrological regime of the river at Lokoja before and after the first dam (Kainji) was commissioned. It was observed that the annual flow during the post-dam period was lower than that of pre-dam period by 10%. This reduction occurred mainly in September, October and November. The seven-day average low flow increased from 520 m^3/s during pre-dam to 800 m^3/s during the post-dam periods, while the fifteen-day average low flow increased from 500 to 850 m^3/s during the respective period. The flood level (Q_{10}) during the post-dam period was lower than the level during pre-dam. This observation shows that one of the effects of river regulation on low flow at Lokoja is to mitigate the severity of low flows, as well as to reduce maximum daily peak flow. It was also discovered that there were variations in the baseflow (Q_{90}) from the pre-dam to post-dam period. The increase in Q_{90} value during the post-dam period could be attributed to changes in land use and agricultural practices.

1. Introduction

There are two dams (Kainji and Jebba) on river Niger within Nigeria. Kainji dam was commissioned in December 1968 for the purpose of generating electricity. The reservoir has total storage volume of 15 billion cubic metres, with a surface area of 127 km^2. The maximum water surface elevation is 141.9 m.a.s.l., while the normal tail water elevation is 1068 m.a.s.l. The Jebba dam, located 97 km downstream of Kainji dam was commissioned in 1984 to utilize the run-off water from Kainji to generate electricity. The dam has a storage capacity of 3.88 billion cubic metres. The maximum water surface elevation is 103 m.a.s.l. Due to rapid electric demand growth in Nigeria, the government planned among other options to impound River Niger at Lokoja to generate electricity.

Flooding of Niger plain between Kainji and Lokoja in Nigeria, resulting in loss of life and properties is an annual phenomenon. Downstream impacts of dams are unrecognised, misunderstood or underestimated by planners (Adams, 2000). This is because flooding phenomena occur in remote areas, and far from the dam site. In addition, downstream impact is daunting in their complexity in space and time. Dam projects are particularly vulnerable to artificially narrow assessment in this way. For example, assessment of the viability of the Bakolori Dam and irrigation scheme in Nigeria specifically excluded consideration of the downstream impacts, and assessment of the Pangue Dam on the Bio-Bio River in Chile in the early 1990’s ignored its dependence on other dam projects (Adams, 2000). Hydroelectric dams are designed to create a constant flow through turbines, and therefore tend to have a similar effect on discharge patterns. However, if the intention is to provide power at peak periods, variations in discharge of considerable magnitude can occur over short time scales, creating artificial freshets or floods downstream. The critical point is that most dams

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moderate and delay the incoming flood peak because of the flood routing effect of the storage impoundment. Such effects can be particularly significant where river regime is flashy, for example river regime in the semi-arid tropics.

This study is aimed at identifying the effect of major dams (Kainji and Jebba dams) on the hydrological regime of River Niger at Lokoja. The result will be useful in understanding the occurrence of flood along the Niger plain, as well as low flow conditions in the river.

2. A review of the hydrology of River Niger

River Niger is the third largest river in Africa. The river runs over 4000km across West Africa. Its basin covers about a third of the land area of the sub-region, extending over 9 countries – Guinea, Cote d' Ivoire, Mali, Burkina Faso, Niger, Benin, Nigeria, Cameroun and Chad. The river takes its source less than 250 km from the coast, from the highlands of the Guinea-Sierra Leone border, in the wet equatorial region (Fig. 1). River Niger, by its peculiar course, first loses the advantage of having its source in a wet climatic region, before turning toward the sea. However, in its middle and lower courses, the river receives many tributaries which argument its volume. These tributaries mostly have their sources in the sub-humid Savanna region and their flows are very much subject to the highly variable and seasonal rainfall regime (Areola and Akintola, 1995).

Rainfall is concentrated in the headwaters and near the outlet of the Niger system within Nigeria. The seasonal pattern is reasonably similar over most of the areas, with maximum in August and a dry season centred on December to February period. However, in southern Nigeria as well as in northern Cameroun, the maximum rain is recorded in July or September. The balance between rainfall and evaporation determines the river flow regime. Consequently, the river exhibits, at certain sections, different regime types and anomalies, which reflect the climatic and physiographic characteristics of the component sub-basins. Two distinct floods (black and white) occur annually in the river. The floods are separated by a period of 4 to 5 months. The black flood originates from high rainfall area in the headwaters. The flood arrives at Kainji in November and lasts until March at Jebba after attaining a peak in February (Oyebande, 1995). The white flood becomes prominent only downstream of Sabon-gari soon after the river enters Nigeria. Usually heavy-laden with silt and other suspended particles. The flood derives its flow from the local tributaries and reaches Kainji in August in the pre-dam period, and attains peak between September and October in Jebba.

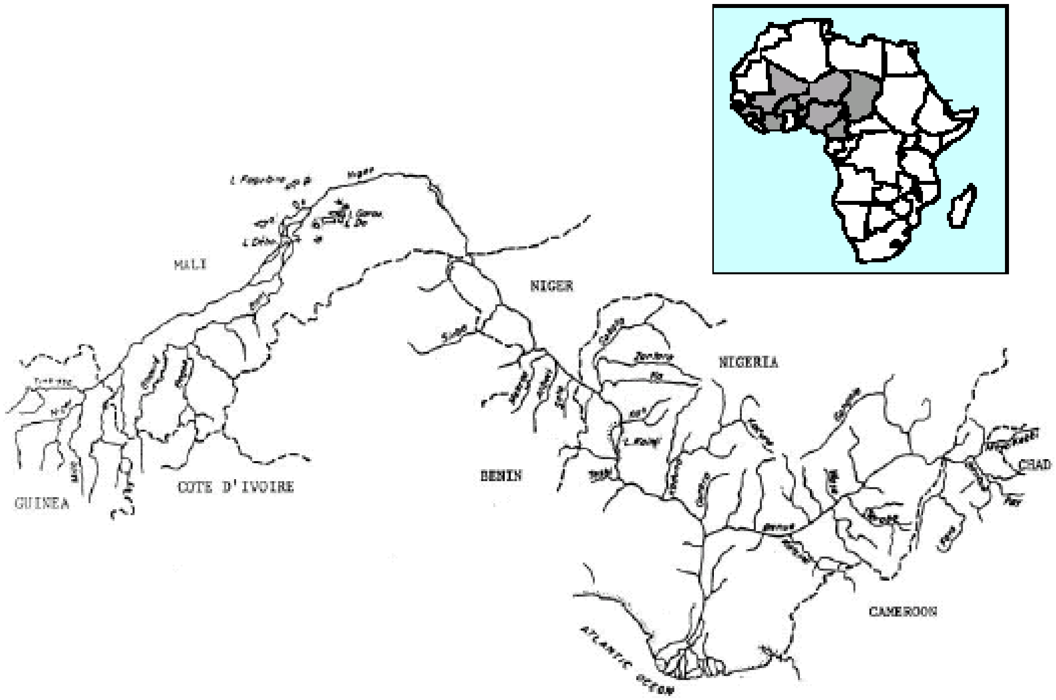

Figure 1: Rivers and Lakes of the Niger – Benue system

3. Methodology

Daily streamflow at Lokoja from 1914 to 2003 was collated (Source: Hydro Niger, Niamey) for this study. Daily rainfall records from the synoptic stations within Nigeria (Table 1) contributing to River Niger at Kainji and Lokoja were also collated. The streamflow record was divided into the pre-dam (1914 – 1963) and the post-dam (1964 – 2003) periods. The characteristics of flow during the pre-dam period were compared with those of the post-dam period. The elements considered are monthly flow, annual flow index, flow duration curve as well as 7-day and 15-day low-flow parameters.

The annual flow index was expressed as the difference of the annual flow from the mean of the 1931 to 1960 flow series, and normalized by the standard deviation of the 1931 to 1960 flow series. The period 1931 to 1960 was considered as the climatological normal for the region. The annual base daily flow duration curve (Vogel and Fennessey, 1995) was used to assess the percentage of times certain flow levels were exceeded. The low flow frequency curves were determined for 1-day, 7-day and 15-day mean flow based on Wallace and Cox (2002).

Table 1: Summary of data collated

Station	Type of data	Location
Sokoto	Daily rainfall	13° 05′ 5° 15′
Gasau	Daily rainfall	12° 10′ 6° 40′
Yelwa	Daily rainfall	10° 52′ 4° 45′
Samaru	Daily rainfall	11° 11′ 7° 38′
Kaduna	Daily rainfall	10° 36′ 7° 40′
Minna	Daily rainfall	09° 35′ 6° 33′
Bida	Daily rainfall	09° 06′ 6° 01′
Ilorin	Daily rainfall	08° 28′ 4° 35′
Lokoja	Daily streamflow	07° 48′ 6° 44′

4. Results and discussion

The flow indices for annual flow series, July to October as well as November to February seasonal flow at Lokoja are presented in Figure 2. The figure shows that the flow during the post–dam period was persistently below the long-term mean. This pattern differed from that of pre-dam period. On the average, the mean annual flow during the pre-dam period was 10% higher than that for the post-dam period. During the July to October season for example, the flow index was greater than 1.0 between 1914 and 1930, indicating high flow in the river. Between 1961 and 1970, that is, before Kainji dam was commissioned and immediately after its commission, the flow index was greater than 1.0. However, the flow index was lower than –1.0 during the period 1971 to 2000. Similarly, Sule (1992) analysed inflow between 1970 and 1987 to Kainji and reported that there was a persistent decline in the inflow to Kainji. The low flow observed at Lokoja and Kainji during the period 1971 to 1990 agreed with the rainfall pattern in the catchment (Figure 3). Nicholson (1981), Adefolalu (1986), Hulme (1992) as well as Jimoh and Webster (1996) among others reported that Nigeria was affected by drought between 1970 and 1980. The drought was characterized by a reduction in depth of annual rainfall. The drought was named ‘Sahelian drought’ indicating the source (Sahel) of the wind causing it. The streamflow level was low during the phenomenon.

The rainfall index, presented in Figure 3 shows that rainfall was above the long-term mean in the 1990’s, but the flow index remained persistently lower than the mean. A similar observation was obtained for the rainfall catchment at Lokoja. The implication of this observation is that flow level at Lokoja is affected by a complex relationship between regulation policies at Kainji (from 1963) and Jebba (from 1986), climatic variation as well as changes in land use pattern and diversion activities at the upstream. Although, there was an increase in rainfall in the 1990’s, the influence of other factors (such as land use pattern, changes in agricultural practices) overshadowed the increase in rainfall level.

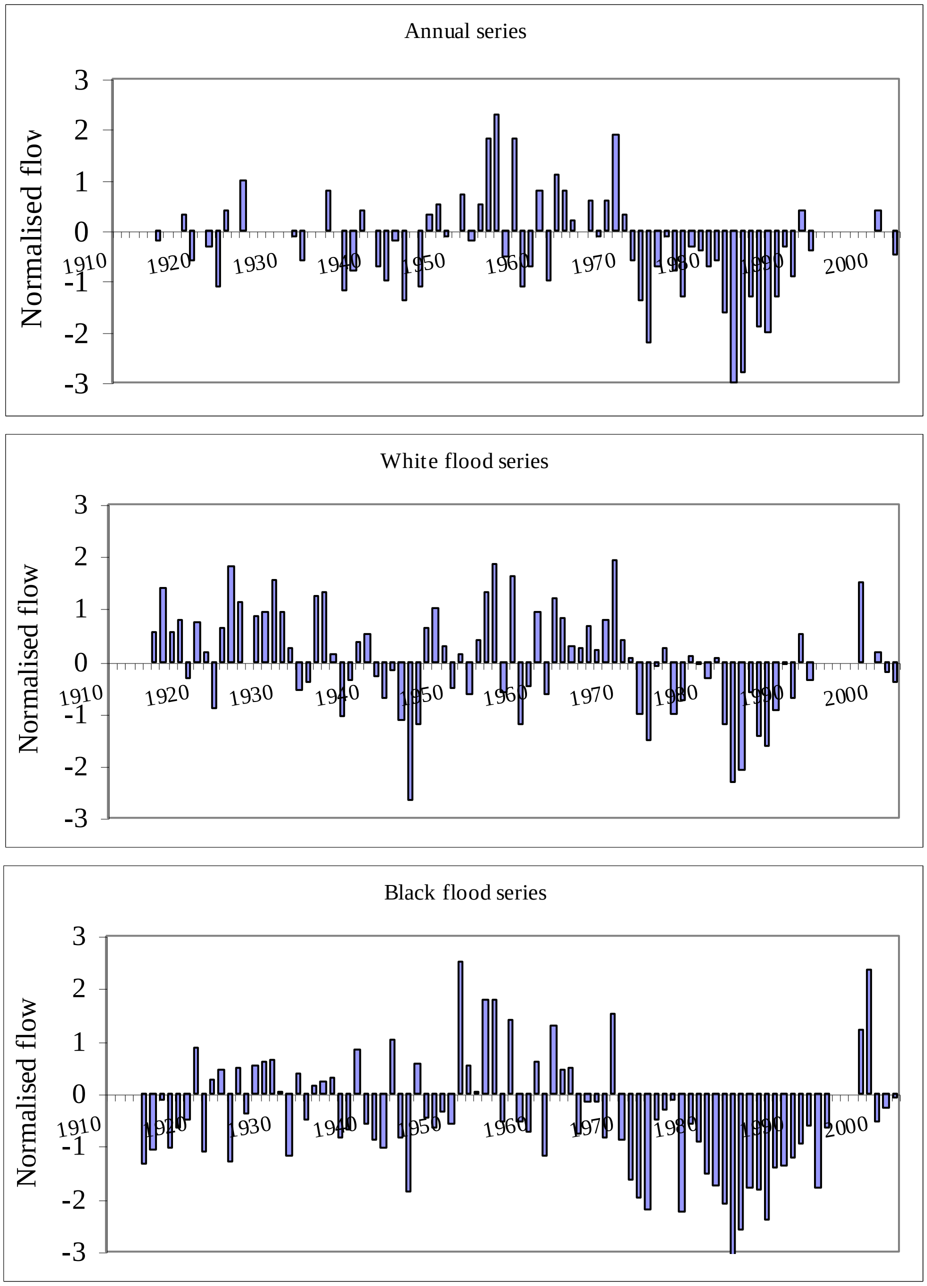

Figure 2: Variation of flow indices at Lokoja

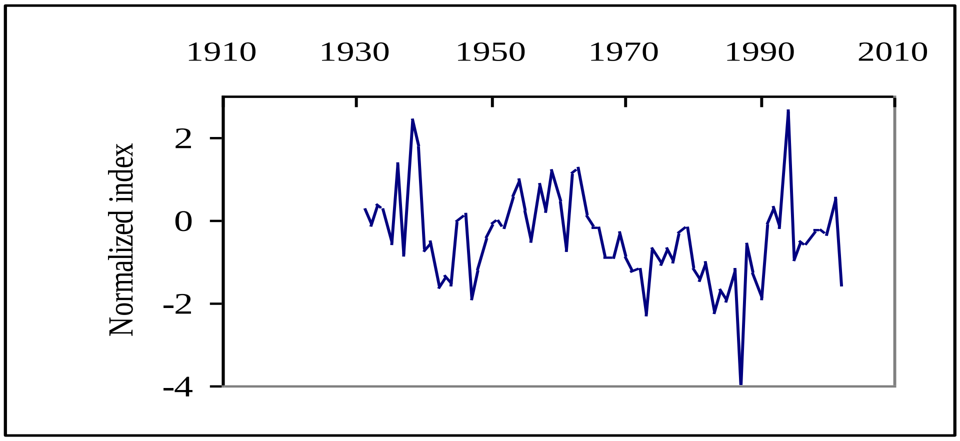

Figure 3: Mean Catchment rainfall at Kainji

Figure 4 shows the frequency curves for 1-day, 7-day and 15-day mean flow at Lokoja. The frequency curves for post-dam period differed from those of the pre-dam period, especially at higher return period. The *1Q10*, *7Q10* and *15Q10* were estimated as 600, 520 and 500 m^3/s respectively during the pre-dam period. The corresponding values during the post-dam era were 700, 800 and 850 m^3/s respectively. While the flow level decreased with averaging length during the pre-dam period, the flow level increased with averaging length during the post-dam era. In particular, the lowest seven-day average flow expected to occur once in ten years (*7Q10*), which represents a relatively infrequent drought conditions, increased from 520 to 800 m^3/s during pre-dam to post-dam periods. Thus, the effect of river regulation on low flow at Lokoja is to mitigate the severity of low flows, which agrees with findings in southern Australia (McMahon and Finlayson, 2003; Lenz, 2004).

The annual maximum daily peak series is presented in Figure 5. For return period ranging between 1 and 14 years, the flood levels during the post-dam period were lower than levels during the pre-dam. This observation has confirmed that, dams upstream reduced peak flow levels (Adams, 2000).

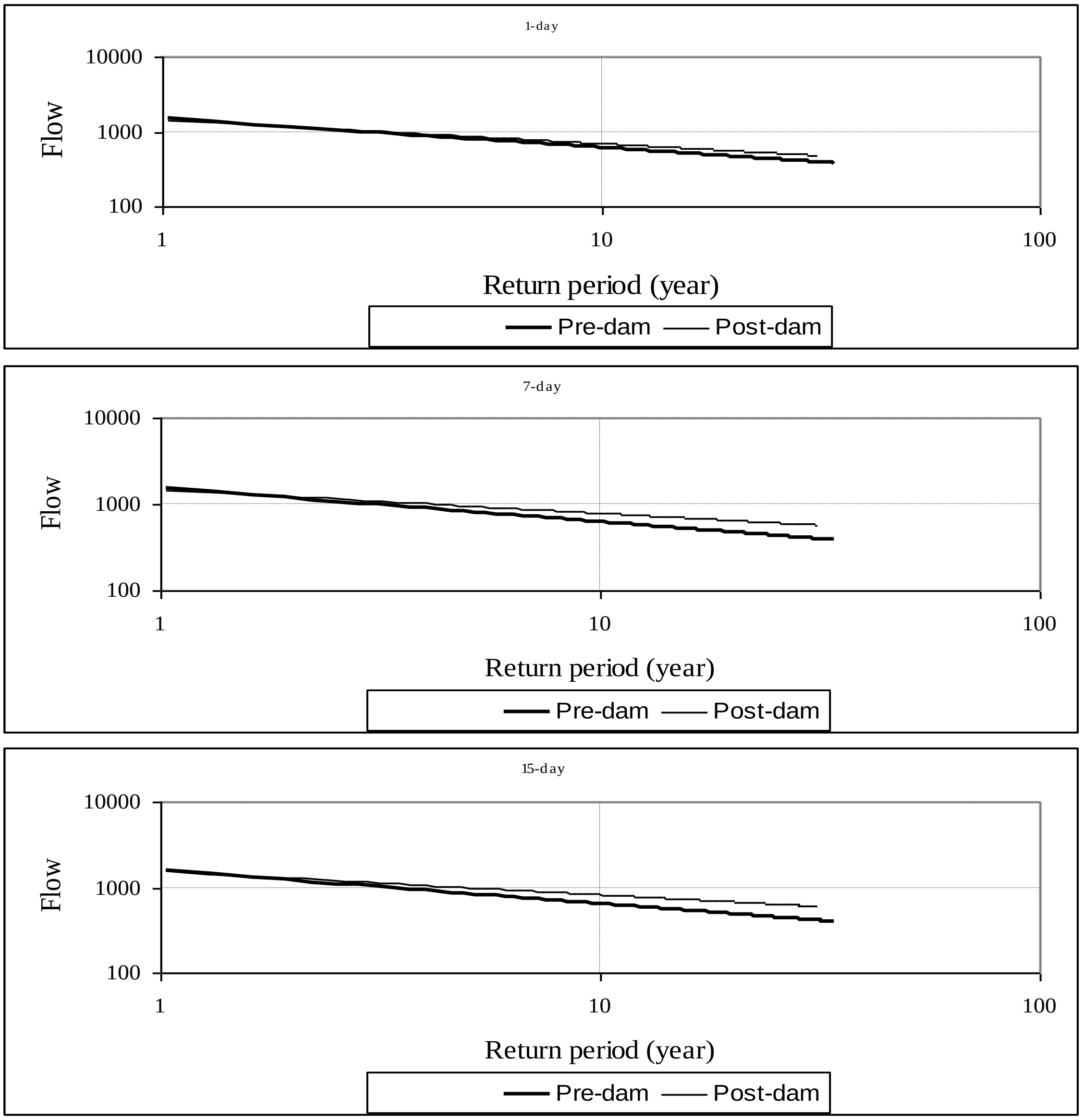

Figure 4: Low flow (in m^3/s) frequency curves at Lokoja

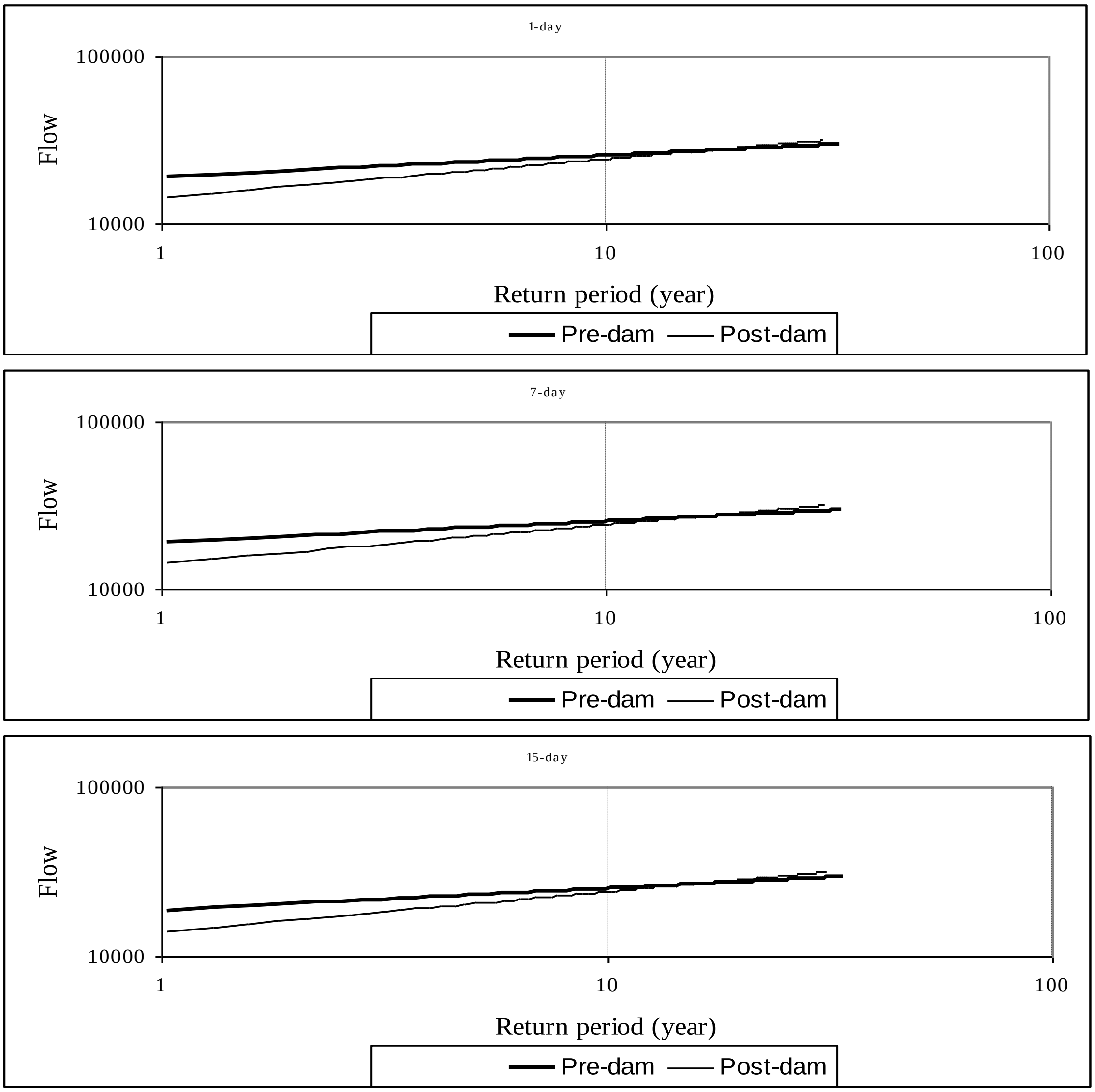

Figure 5: Annual maximum daily flow (in m^3/s) of river Niger at Lokoja

The monthly flow at Lokoja (Figure 6) shows a single peak occurring in October during the pre- and post-dam periods. Double peak seasons (black and white floods) are recorded in Kainji. The difference in flow regime is not due to the operation of the two hydro-dams (Kainji and Jebba), but as a result of the climatic and physiographic characteristics of the sub-basin that contributes to the flow (Oyebande, 1995). The reduction in annual flow at Lokoja during the post-dam period occurred mainly in September, October and November.

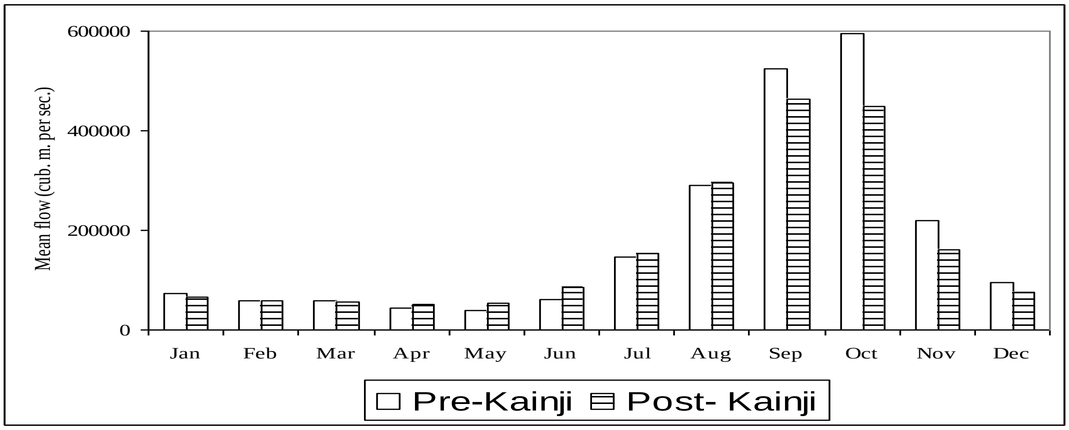

Figure 6: Average monthly flow series of river Niger

Figures 7 and 8 show the flow duration curves for selected years during the pre- and post-dam periods respectively. During the pre-dam period, the Q_{50} (the flow that has been equalled or exceeded 50 percent of time) ranged between 2552 and 4295 m^3/s, with an average of 3109 m^3/s. During the post-dam period, the value ranged between 1654 and 4186 m^3/s, with an average of 2869 m^3/s. During the post-dam period, there was a reduction (7.8%) in the mean value, with a high variability from year to year in the Q_{50} value. The Q_{90} streamflow parameter, referred to as the conservative estimator of mean baseflow (Wallace and Cox, 2002) ranged between 999 and 1771 m^3/s during the pre-dam period, and between 1033 and 1703 m^3/s during the post-dam period. The mean value of Q_{90} is 2651 for pre-dam and 3014 m^3/s for post-dam period. The mean Q_{10} is 18225 m^3/s for pre-dam and 14889 m^3/s for post-dam period, indicating a reduction of 18.3%. This implies that the flood level at Lokoja during the post-dam period is lower than that of the pre-dam period. The curves for both the pre- and post-dam periods flattened at the lower part, indicating a considerable contribution of baseflow and flood plain storage to streamflow. This is reflected in the Q_{90} streamflow parameter. The difference between the groundwater contribution during the pre-dam and post-dam period could be attributed to changes in land use and agricultural practices resulting in improved infiltration rate.

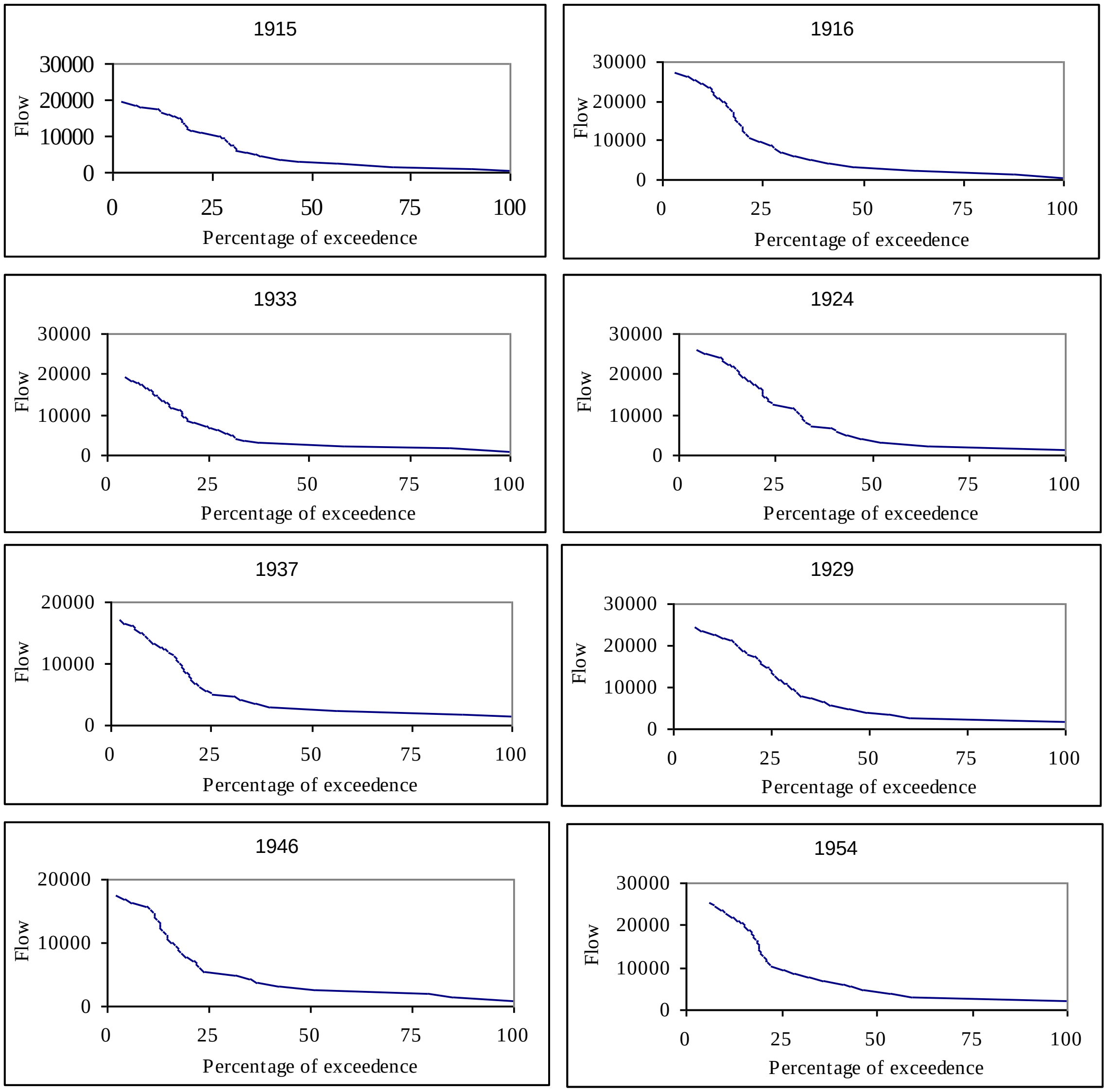

Figure 7: Flow duration curve at Lokoja during the pre-dam period (flows in m^3/s)

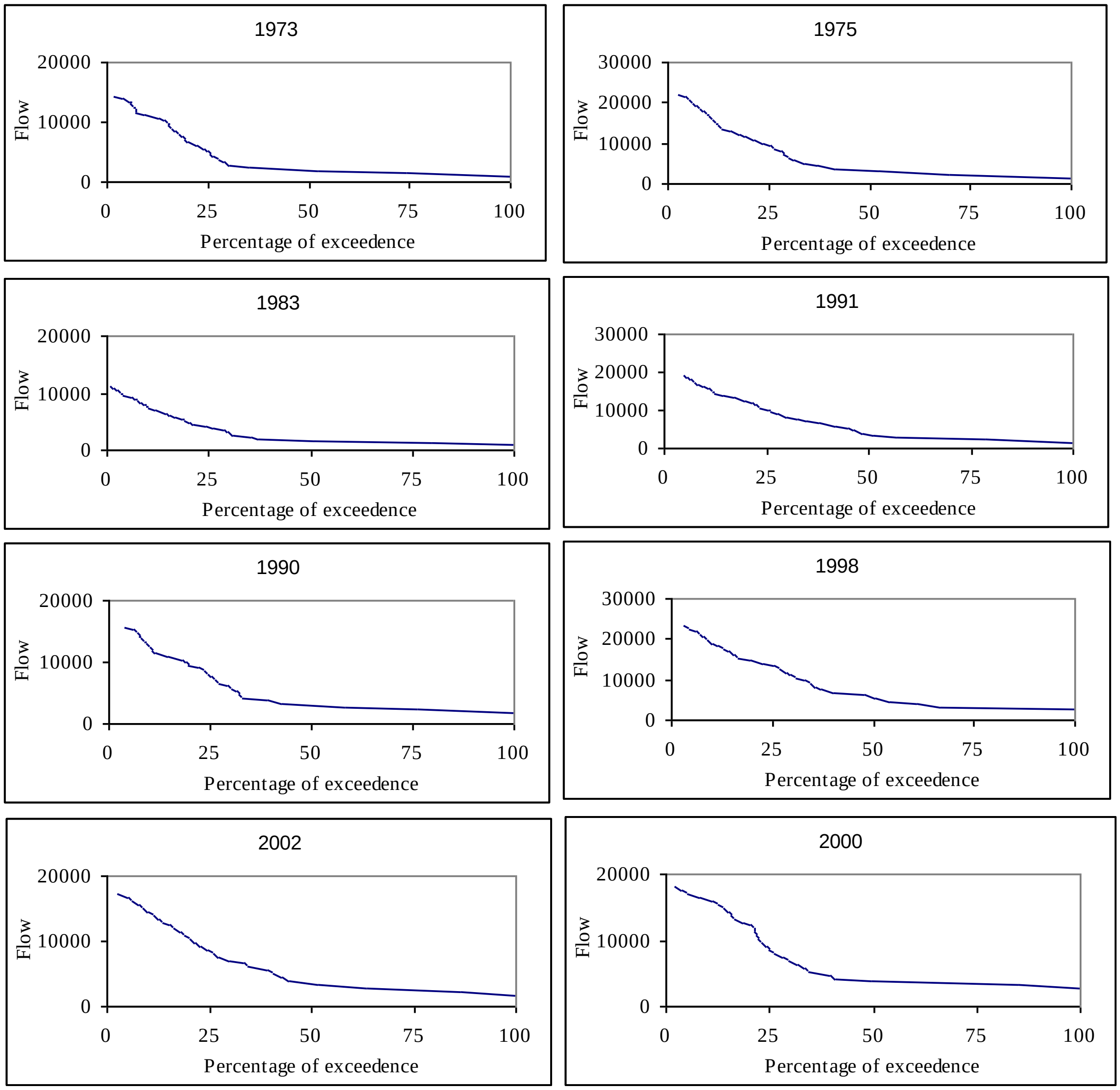

Figure 8: Flow duration curve at Lokoja during the post-dam period (flow in m^3/s)

5. Conclusions

The conclusions of this study are summarised as follows:

The flow at Lokoja has been lower than the long-term mean since 1970. The low level was attributed to low rainfall within the catchment in Nigeria that contributes to the streamflow, the impact of Kainji and Jebba dams, as well as changes in land use pattern within the catchment. The mean annual flow during the pre-dam period exceeded the value for post-dam period by 10%. The reduction in flow occurs mainly between September and November.

The groundwater contribution to streamflow during the pre-dam period differed from that of the post-dam period. This difference was attributed to changes in agricultural practices and land use pattern.

The lowest seven-day average flow expected to occur once in ten years (7Q10), which represents a relatively infrequent drought conditions, increased from 520 to 800 m^3/s during pre-dam to post-dam periods. Thus, the dams at the upstream section of Lokoja mitigate the severity of low flows.

References

Adams, W. (2000). Downstream impacts of dams. Contributing paper to the World Commission on Dams. Prepared for Thematic Review 1.1: *Social Impacts of Large Dams Equity and Distributional Issues*. UK, University of Cambridge.

Adefolalu, D. O. (1986). Rainfall trends in Nigeria. *Theoret. and Appl. Climat*. **37**, 205 - 219

Areola, O. and F. O. Akintola (1995). The Niger River basin in geographical perspective. In: *Global Climate Change – Impact on energy development* (ed. by Umolu, J. C.), 15 – 17. Damtech Publications, Jos, Nigeria.

Hulme, M. (1992) Rainfall changes in Africa: 1931 - 1960 to 1961 - 1990. *Int. J. Climatol*. **12**, 685 - 699.

Jimoh, O. D. and P. Webster (1996) Optimum order of Markov chain for daily rainfall in Nigeria. *J. Hydrol*. **185**, 45 -69.

Lenz, B. N. (2004).Analysis of streamflow and water-quality data at two long-term monitoring sites on the St.Croix River, Wisconsin and Minnesota. *USGS Water Resources Investigations Report 03 – 4334*. United States Departments of Interiors and Geological Surveys.

Mcmahon, T. A. and B. L. Finlayson (2003). Droughts and anti-droughts: the low flow hydrology of Australian rivers. *Freshwater Biology*. **48**(7), 1147.

Nicholson, S. E. (1981) Rainfall and atmospheric circulation during drought periods and wetter years in West Africa. *Monthly Weather Rev*. **109**, 2191 - 2208.

Oyebande, L. (1995). Global climate change and sustainable water management for energy production in the Niger basin of Nigeria. In: *Global Climate Change – Impact on energy development* (ed. by Umolu, J. C.), 18 – 26. Damtech Publications, Jos, Nigeria.

Sule, B. F. (1992). Some aspects of water management in hydroelectric power generation. *The Nigerian Engineer*, **27**(3), 10 – 17.

Vogel, R. M. and N. M. Fennessey (1995). Flow duration curves II: A review of applications in water resources planning. *Water Resour. Bull. of the American Water Resources Association*. **31**(6), 1029 – 1039.

Wallace, T. B. and W. E. Cox (2002). Locating information on surface water availability in Virginia. http://www.rappriverbasin.va.us/studies/locatingsurfacewaterinfo.doc accessed on 10 October, 2004.