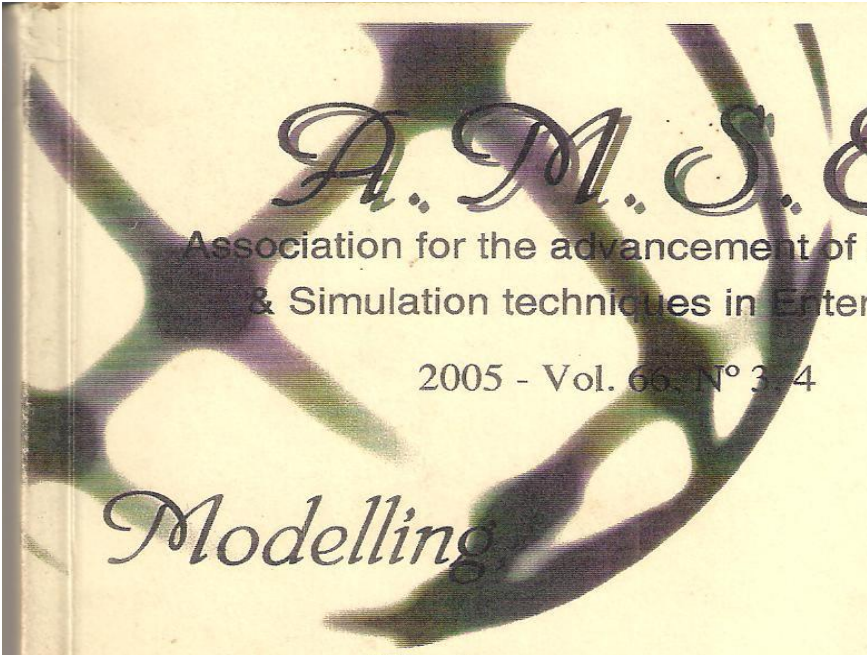




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Simulation of Hydrologic Flood Routing for downstream of Jebba dam using Muskingum Technique

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Abstract

The development of hydrological flood routing along River Niger channel (below Jebba dam), Nigeria was attempted using Muskingum technique. This study involves collection of rainfall data, reservoir inflow, turbine and spillway discharge, in order to perform the routing analysis effectively the river channel was divided into reaches according to the natural watershed of the river and the runoff due to catchment within the reaches along the river channel was estimated using rational method. The data collected were used in Muskingum flood routing technique to predict the temporal and spatial distribution of flood wave (outflow hydrograph) as it travels along the river channel. The Muskingum routing coefficients C_0 , C_1 and C_2 , the travel time of flood wave in a reach (k) and the dimensionless weighting factor X associated to Muskingum routing technique were obtained. The values of the outflow for each reach differ slightly, but the hydrographs show the same pattern with maximum flow occur between the months of September and October as depicted by the outflow hydrographs. The peak and low flows for the downstream of Jebba dam were obtained from the combined outflow hydrograph as $5.20 \times 10^9 \text{ m}^3$ and $2.14 \times 10^9 \text{ m}^3$ respectively.

Keywords

Niger River channel, Downstream of Jebba dam, Hydrologic flood routing, Routing techniques, Muskingum equations and Flood hydrographs

1. Introduction

Flood is one of the most destructive acts of nature that is threatening our contemporary world. Chatlerton et al (1979) stated that if flood can be predicted in advance; then suitable actions can

be taken to mitigate some of its hazards. In practical applications, flood prediction involves two steps. First, a flood routing model (usually hydrologic) is used to obtain the flood peak by routing flood events between stream flow gauging stations. The flood peak is then input into steady, gradually varied flow hydraulic model based on detailed channel geometry in order to forecast flood levels at key locations. This means that there are two possible approaches to the flood routing components available to engineers, namely: hydraulic and hydrologic flood routing techniques, (McKay, et al, 1996). Hydraulic routing uses both the equation of continuity and the equation of motion, while hydrologic routing employs the equation of continuity with either an analytic or an assumed relation between storage and discharge within the system. McKay et al (1996) revealed that hydraulic routing can be used successfully to determine discharge hydrographs in reaches where little channel geometry data are available by approximating the modeled reach by a rectangular channel, but does not accurately predict the associated water levels; Black burn and Hicks (2001) have developed a hybrid modeling approach to overcome this limitation of approximating channel geometry which leads to inaccurate prediction of water level in hydraulic routing. Mc Cuen (1998) revealed that the applications of hydrologic routing techniques to problems of flood prediction, evaluations of flood control measures and assessments of the flood effects on urbanization are numerous, the methods under this technique include:- Muskingum, SCS convex, Att - Kin and Cunge. Hughes (1994) and Mc Cuen (1998) revealed that Cunge developed a routing method that is more flexible than convex, Att – Kin and Muskingum routing methods. It was shown that under certain conditions; Cunge’s development is equivalent to the Muskingum method, thus it is referred to as the Muskingum – Cunge method. Variations of Cunge’s development from Muskingum method is that he uses physical characteristic to compute the coefficients, rather than some arbitrary, empirical approach used for estimating X for the Muskingum method. Salami (2000) developed hydrologic flood routing along Asa river channel, downstream of Asa dam in Ilorin, Nigeria. He adopted Muskingum method of channel routing and the outflow hydrograph shows that the discharge from the dam was eminent at the upstream of the catchments area towards the Ilorin Township. The causes of flood were identified to include constriction of the flood plain due to the development of infrastructures along the banks of the river channel and the indiscriminate dumping of refuse inside the river channel. Salami (2003) studied the flow along Asa River, Nigeria and established probability distribution models for the prediction of annual flow regime. It was deduced that

Log-Pearson type III is suitable for the prediction of minimum flow, while Gumbel extreme value type I is suitable for the prediction of maximum flow. Salami et al (2004) simulated hydrological flood routing for downstream of Jebba hydropower dam. In their work Muskingum technique was adopted to predict the temporal and spatial distribution of flood wave (outflow hydrograph) as it travels along the river channel. The outcome of the study revealed that the peak and low flow volumes for the downstream of Jebba dam are $5.20 \times 10^9 \text{ m}^3$ and $2.14 \times 10^9 \text{ m}^3$ respectively. Salami and Adebayo (2004) also developed a flood forecasting model for downstream of Kainji hydropower dam, Muskingum technique was also adopted to predict the flow pattern. The storage constant k and dimensionless weighting factor x were determined to be 1360.5 sec. (24mins) and 0.2 respectively. The peak and low flow volumes for the downstream of Kainji hydropower dam are obtained from the combined outflow hydrograph as $4.35 \times 10^9 \text{ m}^3$ and $1.35 \times 10^9 \text{ m}^3$ respectively. Wang (2002) worked on flood forecasting model for the west River of the Pearl River Basin, the model was applied at a case study area from Jiangkou station to Wuzhou station of the Lower West River, a tributary of the Pearl River in the South of China. The research aimed at making discharge forecasting project at the Wuzhou station based on both rainfall – runoff model and channel flood routing because the main channel and three tributaries made up of several lumped inflow and distributed inflow. Terry (2002) worked on developing a flood forecasting model for the Welland and Glen Rivers in East Anglia, UK. The model generates runoff hydrographs from inputs comprising measured rainfall and evaporation time series. Boroughs and Zagana (2003) developed a daily flow routing with the Muskingum-Cunge method for the Pecos River. The major efforts for development of water operations model for the Pecos River in New Mexico was to implement a routing methodology that would appropriately represent flood wave travel times (translation) and reduction in peak discharge (attenuation) of flood waves. The Muskingum-Cunge method was selected as a routing method to add to the water operations model, but it was coded in a different manner than it is conventionally coded in other models. The water operations model was developed with the River Ware software application that is a general river basin modeling tool that runs in an object-oriented modeling environment. The software selected to simulate the Pecos River surface water resources from Santa Rosa Lake to Avalom Dam is River Ware (Zagana, et al, 2001) developed by the center for Advanced Decision Support for Water and Environmental Systems (CADSWES) at the University of Colorado at Boulder.

The development of hydrologic flood routing along River Niger (downstream of Jebba dam) is due to annual flooding experience by the communities and irrigation projects located downstream of the dam as a result of indiscriminate discharge from the dam especially during the peak of raining season when its embankment is threatened to be over topped. The routing analysis enables the prediction of flood (generation of outflow hydrographs) along the River channel based on the information available at the upstream reaches.

2. Methodology

2.1 Collection of data and topographic map

Monthly Rainfall data, Reservoir inflow, Turbine and spillway discharges (Reservoir outflow) were collected at the hydrological department of Jebba hydropower dam. The data covers a period of twenty years (1984 - 2003), the average values corresponding to each month is presented in Table 1. A topographical map was obtained for Jebba S.E (Sheet 181 S.E) from the Federal Ministry of Land and Surveys in order to determine the reaches and basins downstream of the dam. From the map, the catchments area of the River downstream of the dam was traced out and sub-divided into twenty reaches (1-20) and basins (A-T) according to the natural watershed of the river; the area of each basin was estimated with the aid of planimeter and presented in Table 2.

2.2 Flood routing analysis

Muskingum method was adopted in analyzing the flood along the River Niger below Jebba hydropower dam. The use of Muskingum technique involved determination of constant X known as the weighting factor expresses the relative contribution of inflow (I) and outflow (O) to storage (S). For a simple reservoir, $X = 0$ (inflow has no effect), while if inflow and outflow were equally effective, $X = 0.5$ (Mc Cuen, 1998). The constant K , known as the storage constant is the ratio of storage to discharge and has the dimension of time. It is approximately equal to the travel time through the reach. The graphical approaches to determine X and K involves plotting

Table 1 Mean values of Rainfall, Reservoir inflow and Reservoir outflow (Turbine and spillway discharge)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean rainfall (mm)	0	0.55	7.36	63.44	137.02	226	168.34	191.25	211.39	91.48	0.44	0
Mean reservoir inflow, I (m ³ /s)	1237.4	1212.6	1034.2	1014.4	905.1	859.3	822.1	1039.9	1855.8	1958.6	1121.3	1177.2
Mean turbine discharge (m ³ /s)	1240.6	1243.7	1032.6	1011.7	886.6	878.7	824.4	1086.1	1491.7	1454.8	1116.2	1114.3
Spillway discharge (m ³ /s)	-	-	-	-	-	-	-	-	722.28	887.9	206.6	-

Table 2 Shows the Reaches, Basins and Catchments area

Reaches	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Basins	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Catchment area x 10 ³ (ha)	5.2	10.2	4.2	2.4	22.6	21.2	17.2	22.3	21.1	5.6	2.1	24.5	4.5	3.8	6.3	5.8	11.3	10.3	11.2	9.5

of storage volume (S) versus [XI + (1 - X) O] for various values of X ranging between 0.0 and 0.5. The X value which produces the narrowest loop is the representative value. The storage volume was determined using equation (1) and the value of the weighted discharge [XI + (1 - X) O] for various values of X (i.e. X=0.1, 0.2, 0.3, 0.4 and 0.5) are also computed.

$$S_{t+1} = S_t + \Delta t \left(\frac{I_t + I_{t+1}}{2} - \frac{O_t + O_{t+1}}{2} \right) \quad (1)$$

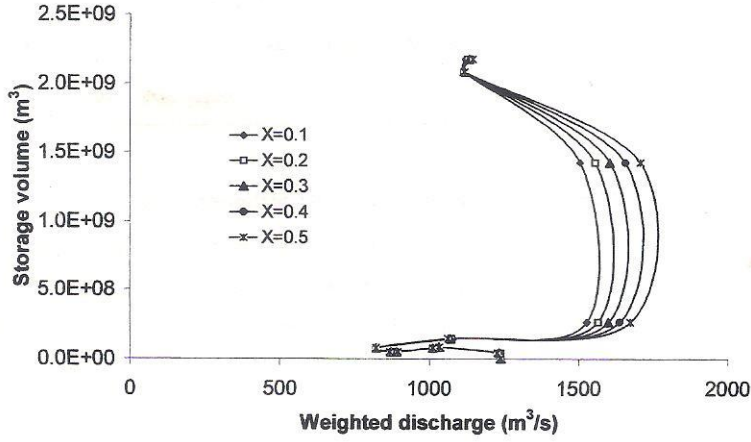
where

S_t is assumed to be zero for the first month (initial condition)

Δt is the time interval (1 month)

The computed storage volume (S) was plotted against the weighted discharge [XI + (1 - X) O] for various values of X and presented in Figure 1. The value of X which produces the narrowest loop was obtained as 0.1 and the corresponding value for K, which is the gradient of the line, was obtained as 680.25 seconds (12 min).

Figure 1 Plot of storage volume versus Weighted discharge



2.2.1 Determination of routing coefficient

The estimation of routing coefficients (C_0 , C_1 and C_2) required the use of X and K , the equations relating the routing coefficients and X and K are given in equations (2) – (4), Wilson (1990) ; Pao-shan and Tseng (1996) and Mc Cuen (1998).

$$C_0 = \frac{-KX + 0.5\Delta t}{K - KX + 0.5\Delta t} \quad \text{-----} \quad (2)$$

$$C_1 = \frac{KX + 0.5\Delta t}{K - KX + 0.5\Delta t} \quad \text{-----} \quad (3)$$

$$C_2 = \frac{K - KX - 0.5\Delta t}{K - KX + 0.5\Delta t} \quad \text{-----} \quad (4)$$

The routing coefficients C_0 , C_1 and C_2 are required in the Muskingum routing technique to generate the outflow hydrograph.

2.2.2 Determination of Runoff

The contribution of the runoff due to the catchments for each reach was estimated using rational formula (Wilson, 1990, Schwab et al (1993) and Mustapha and Yusuf, 1999) as given in equation (5)

$$Q_p = 0.0028 C I_R A \quad \text{-----} \quad (5)$$

where

C = the coefficient of runoff (0 - 1), a value of 0.4 was selected for the reaches since the catchments is covered with grass – vegetation).

I_R = rainfall intensity (mm/hr)

A = the catchments area (ha)

Q_p = peak runoff rate (m^3/s)

2.2.3 Determination of outflow hydrograph

In determining the outflow hydrograph, Muskingum formula was adopted as given in equation (6).

$$O_2 = C_0 I_2 + C_1 I_1 + C_2 O_1 \quad \text{-----} \quad (6)$$

where

C_0 , C_1 and C_2 are the Muskingum routing coefficients

I_1 is the total inflow for the first month

I_2 is the total inflow for the second month

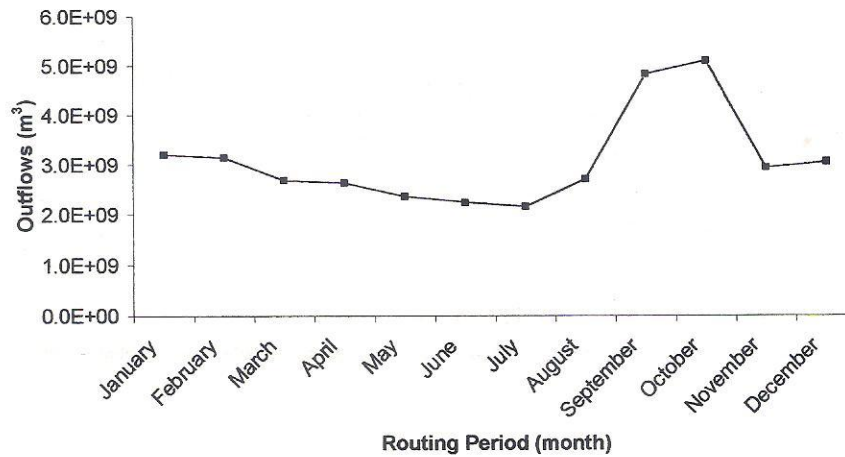
O_1 is the outflow for the first month

Also, for the purpose of analysis $O_1 = I_1$ (Mc Cuen, 1998; Mustapha and Yusuf (1999)).

However, the initial inflow into the river channel (reach 1) is the combination of turbine and spillway discharge for the month, as the water flows through the reach, the discharge from runoff due to catchments area contributing to reach 1 was added to make up the total inflow. The routing analysis was then performed for the first reach. For the second reach, the outflow from the first reach became the initial inflow and the runoff for the catchments of reach 2 was added

and the routing analysis was performed. The routing analysis was repeated for the 20 reaches and the outflows at the end of each reach are plotted against the routing time to establish the form or shape of flood hydrographs, the combined outflow hydrograph for all the reaches is presented in Figure 2.

Figure 2. Combined Outflow Hydrographs



In order to show the behavioral relationship between the observed and routed inflow volumes hydrographs, the values of observed and routed inflow were plotted against the routing time as presented in Figure 3. The observed and routed outflow were plotted against routing time to show the relationship between the observed and routed outflow volumes hydrograph as presented in Figure 4. From Figure 3, it could be deduced that there is a close relationship between the observed and the routed inflow volumes. Also from Figure 4 it could be observed that the routed outflow followed the same pattern as the observed outflow hydrograph with some variations between August and November.

Fig. 3 Mean observed and routed inflow volumes versus routing time

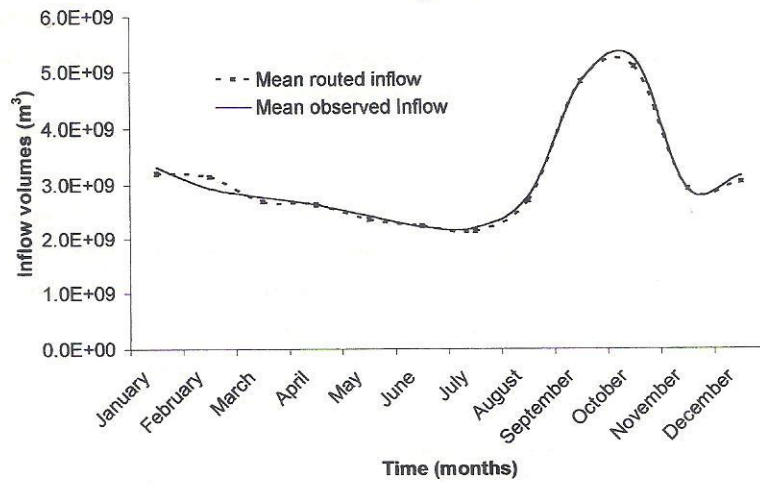
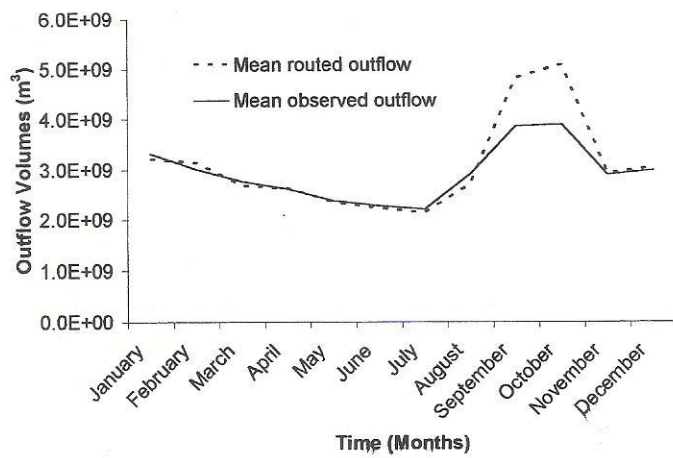


Fig. 4 Mean observed and routed outflow Volumes versus routing time



3. Results and Discussion

The Niger River which is the largest River in Nigeria is used for several purposes, with the generation of hydroelectricity power as the major among its uses. Jebba dam is one of the two dams built across Niger River for hydropower generation and the release from the dam is the major contributor to the flow along the river channel.

The routing analysis was carried out to determine the volume of water to be expected at downstream of the dam (i.e. through the outflow hydrograph) during the months in a year. The routing interval was taken to be one month due to the type of data available at the hydropower station; the rainfall, reservoir inflow, turbine and spillway discharges were on monthly basis as presented in Table 1. In order to facilitate the routing analysis, the catchments area downstream of the dam was divided into twenty reaches based on the natural water shed of the river and their areas were estimated. The reaches and the values of catchments area are presented in Table 2. The dimensionless weighting factor X and the corresponding storage constant K were obtained as 0.10 and 680.25 seconds respectively. The Muskingum routing coefficients, C_0 , C_1 and C_2 were determined to be 0.9995, 0.9997 and -0.9992 respectively.

From the outflow hydrograph it was observed that the peak discharge occurred between the months of September and October, while the low discharge occurred between July and August. This is in agreement with the variation of the mean rainfall value which is at its peak between the months of September and October. Also, from the record at the generating unit, all the turbines used to be put in operation during such months and the spillway always remains open. The estimated peak and low flow volumes for the downstream of Jebba dam were $5.20 \times 10^9 \text{ m}^3$ and $2.14 \times 10^9 \text{ m}^3$ respectively.

4. Conclusion and Recommendation

The Muskingum method of hydrologic flood routing was adopted in the determination of outflow hydrograph at reaches along Niger River channel (down stream of Jebba dam), the outflow hydrograph indicated that the peak discharge occurred between the months of September and October. The creation of the dam has also affected the natural flood plain at the downstream, thus during the peak flow the large quantity of water claim more area as its flood plain hence resulting into flooding. Based on the outcome of this study, the following recommendations are made:

- The inhabitants of the settlements along the river side need to be reminded of the two months identified to be the flood period in order to prevent damages to lives and properties
- The development of infrastructures along the banks of the river channel should be discouraged because it lead to constriction of the flood plains and channel valley
- Structural flood control measures can be introduced along the river channel especially where the towns and villages are too close to the river channel
- Effort should be made at the hydrological unit of the hydropower dam to keep daily data which would ensure more accurate and efficient routing analysis.

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