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Impact Assessment of Mtera and Kidatu Reservoirs on the Annual Maximum Floods at Stiegler's Gorge of the Rufiji River in Tanzania

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***Abstract**: The impoundment of any river causes changes in the downstream flow regime. The effect of a dam on flow regime depends on both the storage capacity of the reservoir relative to the volume of river flow and the way the dam is operated. The most common attribute of flow regulation is a decrease in the magnitude of the flood peaks and an increase in low flows. This paper reports the findings of a study to assess the cumulative impact of two dams on the Great Ruaha River in Tanzania (the Mtera and Kidatu Reservoir System) on flood flows. The method used was to compare the observed annual maximum flows at downstream locations after the construction of the dams with mathematically modeled estimates of the annual maximum flows at the same locations, assuming that the dams were not built (i.e. generating naturalized flows). Contrary to expectations, the study found that annual maximum peaks were supposed to be less than those actually observed. For instance, in 1989, annual maximum peak flow of 1,400 m^3/s was recorded at Kidatu, but the estimated uncontrolled peak flow should have been 800 m^3/s, signifying an artificially-induced flood wave. Although, there was a significant impact on the peak flows at Kidatu owing to the dams, the impact was found to be minimal on the flow peaks at Steigler's Gorge.*

***Keywords**: annual maximum floods, impact assessment, linear transfer function, mathematical modeling, Mtera-Kidatu Reservoir System, Rufiji River Basin*

Introduction

Dams are normally built to regulate natural flows of rivers in order to store water so that it is there when it would not naturally be available. Of course, any deviation of river flow from its natural state in any river system is expected to have an impact on the flow characteristics on its downstream flow pattern. This phenomenon was expected at Stiegler's Gorge and subsequently the floodplain and the delta region of the Rufiji River, due to the existence of the Mtera and the Kidatu Reservoirs upstream of Stiegler's Gorge.

Generally, dams are built to decrease peak flows and increase low flows, and in so doing provide relatively constant flows for power generation at hydroelectric power plants. In addition, some dams are built purposefully to (artificially) induce floods, but the Mtera-Kidatu Reservoir System was not. It was built for power generation. Again, with a good and efficient reservoir operating policy, a reservoir system can be a buffer against floods while ensuring continuous optimum flow during dry spells. The flow pattern, therefore, is essential in hydroelectric power production, especially in meeting the firm power demand.

The Tanzania Electricity Supply Company (TANESCO) controls the outflows from the two reservoirs for power generation, and hence the flows downstream of the two reservoirs are not natural as they used to be before the impoundment of the river. In order to know the impact of the reservoirs on the flow regime and the flood flows, in particular, mathematical models were used principally (Diskin, 1964; Eagleson et al., 1965) to simulate the flow peaks with and without the dams in place.

Hydrological models are basically mathematical models that are used to simulate flow so that the flow can be predicted in different circumstances. The system types of hydrological models (Clark, 1945; Dooge, 1959; Dooge, 1973) were used in this study.

The Study Area

The study area is located at the Rufiji River Basin, the biggest river basin in Tanzania, covering an area of about 20 percent of the mainland Tanzania. The basin has a lot of economic potentialities such as agriculture, national parks, game reserves, and hydropower sources (Danida/World Bank, 1945). Most of the basin lies between 300 m and 2,400 m above mean sea level and has a rolling terrain with rising scalps at the mountainous areas. The mountainous ranges receive a well over 1,400 mm of rainfall annually, while the plain regions are relatively dry with annual rainfall as low as 600 mm.

The main land drains into the Indian Ocean by way of the Rufiji River from three main sub-basins: the Great Ruaha River sub-basin, the Kilombero sub-basin, and the Luwegu sub-basin. The upper-most gauging station on the Rufiji River is at Stiegler's Gorge (1k3), with a drainage area of about 177,000 km^2 and a daily mean flow of 800 m^3/s. Figure 1 shows the location of the reservoir system with the rivers and features of this study area in Tanzania.

Therefore, the three main rivers that contribute to flows at Stiegler's Gorge are the Great Ruaha, the Kilombero, and the Luwegu. Of these rivers, only the Luwegu River is not gauged. However, it has fairly good amount of rainfall gages. Flows for the Great Ruaha and Kilombero are gauged at Kidatu (1ka3) and at Kilombero kwa Sero (1kb17), respectively. The daily mean flow at 1ka3 is 160 m^3/s and that at 1kb17 is 520 m^3/s, while the drainage area for each is 80,040 km^2 and 33,066 km^2, respectively.

Mtera and Kidatu reservoirs were constructed in mid-1980 and in 1976, respectively, on the Great Ruaha River for hydroelectric power generation; with Kidatu Reservoir being located approximately 170 km downstream of Mtera Reservoir. The Mtera Reservoir/Dam is primarily used as storage for the smaller Kidatu Reservoir/Dam, which has higher head for greater power generation. The storage capacity of Mtera Dam is 125 million m^3, which is roughly 25 times larger than the Kidatu Dam. The surface area of Mtera Reservoir is 620 km^2 at full capacity, and it is 8.5 m deep, ranging from 690.0 m to 698.5 m above mean sea level. Corresponding values for the Kidatu Reservoir are a surface area of 9.5 m^2 at full capacity and a depth of 17 m ranging from 433 m to 450 m above mean sea level. The installed capacity at Mtera Dam is 80 MW, made up of two turbines, whereas at Kidatu Dam it is 200 MW, from four turbines. These reservoirs operate as a dual-system and produces over 80 percent of Tanzania's hydropower.

Downstream of this reservoir system in the Rufiji River is the regular recurrence of catastrophic flood disasters in the Rufiji floodplains. History of the dam operation had been pinpointed to be very inefficient (Yawson et al., 2003a; Yawson et al., 2003b), and therefore the determination of the dam operation on annual maximum flows was a necessity.

Method

Using mathematical models as representations of real world, it is possible to simulate natural flow conditions in a river while imposing appropriate constraints. With the use of these models, human impacts on the river system can be quantified. The approach adopted in the study is making use of mathematical models to simulate natural flows (i.e. simulation of flows without the dams in place) and

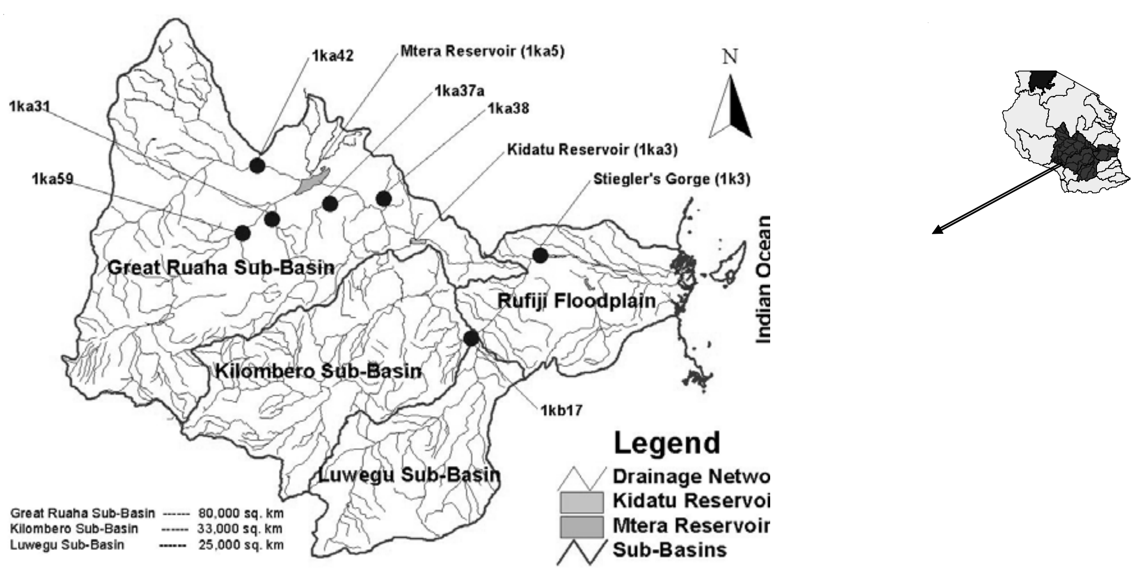


Figure 1. Map of Rufiji River Basin showing the Mtera-Kidatu Reservoir System and flow gauging stations used

compare them with the present situation (i.e. with the dams in place). In other words, the study analyzes the simulation of flows with and without dams present. The overall span for the analysis was from 1957 to 1993; however, the model at Stiegler's Gorge was calibrated using 1958 to 1975 records and verified from 1976 to 1984, and then the model was used to estimates flows up to 1993.

Normally, selections of appropriate models are done by comparison between the models' estimates and the observed data. Obviously, such model estimates are subject to modeling errors and the Nash and Sutcliffe efficiency criterion (R^2) of how much the model accounts for variances between the observed and model estimates is one of the best efficiency criteria applied in hydrological studies, especially in volumetric terms (Nash and Sutcliffe, 1970). The Nash and Sutcliffe efficiency criterion is defined by Equation 1.

$$R^2 = \left(1 - \frac{\sum_{i=1}^{n}\left(Q_i - \hat{Q}_i\right)^2}{\sum_{i=1}^{n}\left(Q_i - \overline{Q}\right)^2}\right) * 100\% \tag{1}$$

where Q_i is the observed discharge, $\hat{Q}_i$ is the estimated discharge, $\overline{Q}$ is the mean of the observed discharge during the calibration period and n is the number of data points.

An equally-important criterion in ensuring maximum extremes (e.g. flood peaks) fitting is the Percent Error in Peak (USACE, 1998) with the following objective function

$$Z = \left|\frac{Q_o(peak) - Q_s(peak)}{Q_o(peak)}\right| * 100\% \tag{2}$$

where Q_o *(peak)* is the observed peak discharge, Q_s *(peak)* is the estimated peak discharge and Z is the objective function. The objective function is not very successful in most hydrological applications owing principally to shift in the magnitude of the estimated peak values most of the times. Percent Error in Volume criterion is most ideal and often used instead and is defined as

$$V = \left|\frac{V_o - V_s}{V_o}\right| * 100\% \tag{3}$$

where V_o is the volume of the observed hydrograph, V_s is the volume of the simulated hydrograph and V is the objective function. The aim of these efficiency criteria is to minimize the V and Z.

By use of special form (a reduced form) of the Linear Transfer Function (LTF) model, comprising one autoregressive and two moving average terms (Beguin et al., 1980), inflows at Mtera, Kidatu, and Stiegler's Gorge were estimated with the respective model's coefficients being optimized by the method of Ordinary Least Squares (OLS) over the calibration period of the models. The method of OLS had been widely documented in literatures (e.g. Kachroo and Liang, 1992), and therefore this paper will not discuss it further. The LTF models can avoid or reduce bias of transfer function weight estimates under rather practical assumptions (Liu, 1991). The structure of the LTF model formation is described by Equation 4.

$$Q_{t+1:k} = \alpha * Q_{t:k} + \sum_{j=1}^{N}\left(\beta_{1:j} * Q_{t+1:j} + \beta_{2:j} * Q_{t:j}\right) \tag{4}$$

where $Q_{t:j}$ is the flow value or effective rainfall at time t of upstream station j; $Q_{t:k}$ is the flow value at time t of the station k; the alphas and betas and the are the parameters of the model; and N is the number of stations contributing to the flow at the downstream station (i.e. on different tributaries).

This special form of the LTF model was chosen because it corresponds to the Muskingum Routing Model (Stephenson, 1979), which has been widely used for channel routing (WMO, 1975; WMO, 1992; Singh, 1995), if the dependent variables do not include rainfall. It had been successfully applied in river flow forecasting on large catchments as well (e.g. Liang and Nash, 1988; Liang et al., 1992). The suitable calibrated models established for modeling river flows at Mtera, Kidatu, and Stiegler's Gorge, respectively, were then used to estimate flows at their respective locations. Same as reported in a study by WREP (2002). The flow estimates derived especially after the construction of Mtera and Kidatu Reservoirs were the hypothetical uncontrolled flow, i.e., flow that would have occurred had there been no impoundment of the river at Mtera and Kidatu. Estimation of the uncontrolled hypothetical flows at Mtera, Kidatu, and Stiegler's Gorge was one of the essential steps in the impact analysis covered in this study.

The LTF models were re-cast into three forms: Simple Linear Model (SLM), Linear Perturbation Model (LPM) and Linear Varying Gain Factor Model (LVGFM), and used to develop "Inflow Models" at Mtera Reservoir, at Kidatu Reservoir, and at Steigler's Gorge. These are explained in details below. These models belong to the system types of hydrological models hinted in the first section of this paper.

These three models are all based on multiple regression equations where the dependent variable is the daily runoff at the downstream location, and the independent variables are daily runoff records at the upstream location(s) and/or average rainfall values recorded within the intervening catchment. While flows are inputted into the models as flow rates, the average rainfall is input in depth units in addition with the area extent. The effects of these inputs into the models are reflected in the coefficients or parameters of the models.

The LPM is a modification of the SLM where seasonal variations in rainfall and runoff are accounted for in the regression equation (Kachroo, 1992; Kachroo and Liang, 1992). The LVGFM is a further extension of the regression equation, where non-linearity due to high intensity of rainfall is accounted for (Shamseldin et al., 1997). All three of these models were used in their parametric

Table 1. Model Efficiency Results for SLM, LPM and LVGFM

Catchment Code Output	Inputs	Calibration Period	Model efficiency (R^2 in %) during calibration SLM	LPM	LVGFM	Verification Period	Model efficiency (R^2 in %) during verification SLM	LPM	LVGFM	Catchment Area (km^2)
1ka5	-1ka31 -1ka42 -1ka59	1957-1975	93.87	90.35	94.26	1976-1979	72.21	69.85	73.53	67,884
1ka3	-1ka5 -1ka37a -1ka38 -Intervening catchment areal rainfall	1958-1969	91.83	92.02	91.98	1970-1975	89.18	89.48	89.68	80,040
1k3	-1ka3 -1kb17 -Intervening catchment areal rainfall	1957-1975	85.58	85.44	86.53	1976-1984	62.26	71.09	63.43	177,000

where 1ka5 – Mtera Reservoir, 1ka3 – Kidatu Reservoir and 1k3 – Stiegler's Gorge; SLM: Simple Linear Model; LPM: Linear Perturbation Model; LVGFM: Linear Varying Gain Factor Model

formulation of the LTF mode. The parameters were estimated by the method of OLS.

Estimation of Inflows into Mtera Reservoir (1ka5)

The three models (SLM, LPM, and LVGFM), in their LTF form, were used to relate the flow at 1ka5 (Mtera) with inflows at 1ka31 (Mawande), 1ka42 (Kisigo), and 1ka59 (Msembe Ferry). The location of these stations can be seen in Figure 1, with the 1ka5 labeled as Mtera Reservoir.

Since Mtera Reservoir was constructed in mid-1980 the models were calibrated for pre-impoundment period of 1957 to 1975. Thus, data of 19 years was used for the calibration of the models, and the data for the remaining four years, 1976 to 1979, was used for the verification of the models. All the three models registered efficiency (R^2) of above 90 percent during calibration, with LVGFM having the highest efficiency of 94 percent and LPM having the least, with 90 percent. The results are presented in Table 1. The same order of efficiency was observed during verification with LVGFM having an efficiency of 74 percent, while LPM had an efficiency of 70 percent.

The SLM, LPM, and LVGFM had a volumetric error of 2.5, 1.1, and 7.1 percent, respectively, during the calibration, as shown in Table 2. LVGFM had the least error of 41 percent in estimating the highest observed peak flow at Mtera, while SLM had the greatest error of 65 percent from the calibration. The calibrated coefficients for the SLM and LPM are presented in Table 3.

SLM was used for estimating inflow at Mtera because the results are not vastly different from the others with very minimal error in volume, and also it is the simplest among the three models. For the sake of discussion, this model is referred to as "Mtera Reservoir Inflow Model." Observed and estimated peak hydrographs at Mtera for the three models are shown in Figure 2a.

Estimation of Inflows into Kidatu Reservoir (1ka3)

River flow data at Kidatu (1ka3) was consistently available from 1954 to 1975; prior to impoundment of the river at Kidatu. Scanty discharge data after impoundment of the river was also available for the period 1982 to 1985, as obtained from the Ministry of Water and Livestock (MoWL), Tanzania. Observed flow at three flow stations; 1ka5 (Mtera), 1ka37a (Lukosi at Mtandika) and 1ka38 (Yovi) were combined with the average rainfall over the intervening catchment to estimate flow at the Kidatu flow recording station.

Table 2. Performance of the SLM, LPM and LVGFM in estimating the Volume and the Highest Peak of the Observed Discharges

Outlet Catchment	Input Catchments	Minimum Observed Discharge (m^3/s)	Maximum Observed Discharge (m^3/s)	Model	Percent Error in Volume, V during Calibration	Percent Error in Peak, Z for Highest Peak
1ka5	-1ka31			SLM	2.49	64.75
	-1ka42	0.17	1,121.90	LPM	1.05	58.96
	-1ka59			LVGFM	7.11	40.58
1ka3	-1ka5			SLM	2.49	52.50
	-1ka37a			LPM	0.02	48.50
	-1ka38	11.31	1,462.60	LVGFM	9.34	27.94
	-Intervening catchment areal rainfall					
1k3	-1ka3			SLM	6.58	38.39
	-1kb17	210.75	6,244.30	LPM	0.48	41.48
	-Intervening catchment areal rainfall			LVGFM	10.92	26.15

Table 3. Calibrated coefficients for the SLM and the LPM as applied in their LTF form

Component	*Order*			*Model coefficients* *SLM*	*LPM*
Mtera Reservoir	Autoregressive procedure		1	0.916082	0.920842
Inflow Model	Moving average	1ka31	2	0.522527	0.507212
				-0.493698	-0.478912
		1ka42	2	2.4789	2.68126
				3.90846	3.99865
		1ka59	2	0.621958	0.619501
				-0.451605	-0.453621
Kidatu Reservoir	Autoregressive procedure		1	0.881805	0.897026
Inflow Model	Moving average	1ka5	2	0.285723	0.267549
				-0.165473	-0.150276
		1ka37a	2	0.258375	0.241200
				-0.163646	-0.110379
		1ka38	2	0.705868	0.693924
				-0.956481	-0.831974
		Intervening catchment	2	0.317916	-0.831974
		areal rainfall		0.358403	0.40229
Stiegler's Gorge	Autoregressive procedure		1	0.916082	0.920842
Inflow Model	Moving average	1ka3	2	0.621958	0.619501
				-0.451605	-0.453621
		1kb17	2	0.522527	0.507212
				-0.493698	-0.478912
		Intervening catchment	2	2.4789	2.68126
		areal rainfall		3.90846	3.99865

The three systems type of models already discussed above (i.e. SLM, LPM, and LVGFM in the LTF form) were calibrated over a period of 18 years from 1958 to 1969. Model verification was done from 1970 to 1975 (six years). Good model efficiencies were obtained, with all models registering an average R^2 of above 91 percent during calibration and 89 percent during the verification period. The results are also presented in Table 1.

LPM had the least error, nearly zero percent, in estimating the observed flow volume, while LVGFM had the largest error of 9.3 percent during the calibration, as shown in Table 2. The calibrated coefficients for the SLM and LPM are given in Table 3. The best highest observed peak flow at Kidatu was estimated by LVGFM with an error of 28 percent. The corresponding error recorded by the SLM was 52 percent. For simplicity, SLM was again adopted for the estimation of inflows at Kidatu. This model is, hereby, referred to as "Kidatu Reservoir Inflow Model" for discussion sake. Observed and estimated peak hydrographs for the three models are as shown in Figure 2b.

Estimation of Inflows at Stiegler's Gorge (1k3)

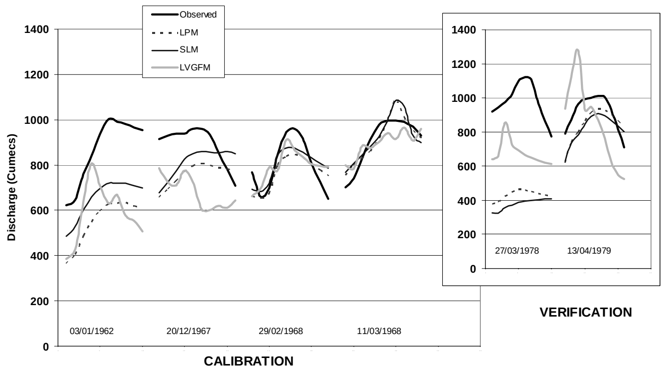
The observed flows at Kidatu (1ka3) and at Kilombero (1kb17) together with the average rainfall over the intervening catchment between Kidatu, Kilombero and Stiegler's Gorge were used to estimate inflows at Stiegler's Gorge (1k3). The Luwegu sub-basin is included in the intervening catchment in this case. Again, the three models were used. The available discharge data at Kilombero (1kb17) was from 1957 to 1984. Average rainfall data over the intervening catchment was available from 1951 to 1996. Observed discharge data at Stiegler's Gorge was available from 1957 to 1985. Calibration period for the three models was chosen from 1957 to 1975 (19 years) while model verification was done from 1976 to 1984 (9 years).

Fairly good model efficiencies were registered for all models during the calibration period with an average R^2 of 85 percent. The results are included in Table 1. LPM had the best efficiency during verification with an R^2 of 71 percent, while SLM and LVGFM had an average efficiency of 63 percent.

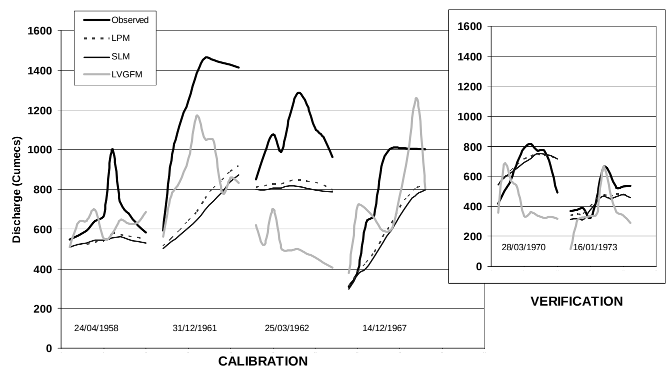
LPM had the least error of 0.5 percent in estimating observed flow volume during the calibration, while LVGFM had the largest error of 10.9 percent, as shown in Table 2, with the calibrated coefficients for the SLM and LPM are given in Table 3. The highest observed peak at Stiegler's Gorge estimated by LVGFM had the least error of 26 percent compared to LPM that had the largest error of 41 percent. Again, SLM was chosen for use in this study owing to its simplicity, and this model is referred to as "Stiegler's Gorge Inflow Model." Observed and estimated peak hydrographs at Stiegler's Gorge for all the used models are shown in Figure 2c.

The Impact Analysis

The analysis was carried out by comparing the hypothetically "observed" annual maximum flows at Stiegler's Gorge after the construction of the reservoirs with estimates of the annual maximum flows at this location assuming that the two reservoirs were not built (i.e. the simulation of the naturalized flows). These quantities of flows were estimated by the use of the mathematical models (i.e. the inflow models discussed above). The data of



(a)



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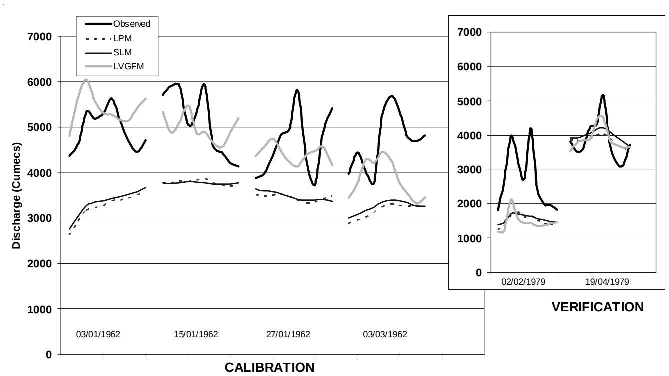

(c)

Figure 2. Comparison of observed and estimated peak hydrographs for (a) 1ka5 (Mtera) - Inputs: 1ka31 (Little Ruaha), 1ka42 (Kisigo) and 1ka59 (Great Ruaha); (b) 1ka3 (Kidatu) - Inputs: 1ka5 (mtera), 1ka37a (Lukosi), 1ka38 (Yogi) and intervening catchment average rainfall; and (c) 1k3 (Stiegler's Gorge) – Inputs: 1ka3 (kidatu), 1kb17 (Kilombero) and intervening catchment average rainfall

outflows at the outlet of the Kidatu Reservoir (1ka3) was obtained from TANESCO for 1983 to 1997. This is the post-impoundment period. It was calculated by adding the machine discharges and the spills on a daily basis, not forgetting that the river was impounded at Mtera in mid-1980 while at Kidatu it was impounded in 1976.

The hypothetical uncontrolled flow, i.e. flow that would have occurred had there been no impoundment at Mtera and Kidatu was estimated for the period of 1980 to 1993 for the Mtera Reservoir and for the Kidatu Reservoir the period was between 1975 and 1993. The hypothetical uncontrolled flow at Mtera (1ka5) was estimated by the "Mtera Reservoir Inflow Model," which was calibrated for the period prior to 1980 when the reservoir was not actually built. The inputs to the model were flows at stations of 1ka31, 1ka42, and 1ka59. The hypothetical uncontrolled flow at Mtera, from 1980 to 1993, was therefore estimated.

The "Kidatu Reservoir Inflow Model" for the estimation of flow into Kidatu Reservoir was used to estimate the hypothetical uncontrolled flows at Kidatu by using observed flows at 1ka37a, 1ka38, intervening catchment average rainfall and hypothetical uncontrolled flow at 1ka5 for the period between 1980 and 1993. The hypothetical uncontrolled flow at 1ka5, for this period, was estimated earlier by using the "Mtera Reservoir Inflow Model."

The operational policy of the hydroelectric power production for the Mtera-Kidatu Reservoir System is to store more water at Mtera Reservoir to produce enough power at Kidatu with the catchment between the two reservoirs constituting about 12,000 km^2 (Yawson et al., 2003a). The storage capacity of Mtera Reservoir is 125 Mm^3, which is roughly 25 times larger than that of Kidatu Reservoir, however the head at Mtera is 8.5 m and that at Kidatu is 17 m. The production capacity at Mtera and Kidatu are 80 MW and 200 MW, respectively. In times of excess flows upstream of the reservoir system, spillway gates are opened to create unexpected flooding downstream to prevent dam damage.

The annual maximum flows observed at Kidatu between 1983 and 1993 were compared with the estimated hypothetical uncontrolled annual maximum flows at Kidatu. It was noted that high floods were induced by releases from Kidatu. In 1989, for instance, an annual maximum peak flow of 1,400 m^3/s was recorded. The estimated uncontrolled maximum peak flow for that year is only about 800 m^3/s. This is an interesting observation, as one would normally expect attenuation of peak floods rather than accentuation of floods resulting from impoundments. Given that the Kidatu Reservoir is of small capacity and the TANESCO that operates the reservoir does not have a proper flow forecasting system in place (Yawson et al., 2003b), it seems that when a large flood wave enters the reservoir the operators of the reservoir system let the water go at the maximum capacity. The result is, therefore, equivalent to an artificially induced flood wave. This is a phenomenon that can easily happen under inefficient management of the reservoir system (Yawson et al., 2003a).

To assess the impact of the Mtera-Kidatu impoundment on flow at the Stiegler's Gorge, the following procedure was adopted:

(a) The sub-catchment model (Stiegler's Gorge Inflow Model) for estimating flows at Stiegler's Gorge (calibrated for the period 1957 to 1975, i.e., the period prior to the impoundment of water at Kidatu) was used to extend the flow at the Stiegler's Gorge beyond 1984, because there were no observed records at the Stiegler's Gorge beyond 1984. The inputs to this model were observed flow, i.e., the controlled outflows, at Kidatu (the reservoir releases at Kidatu), observed flow at Kilombero, and the observed intervening rainfall.

(b) The same "Stiegler's Gorge Inflow Model" was used to estimate flow at the Stiegler's Gorge beyond 1975 assuming a hypothetical situation of no impoundment at Mtera and Kidatu. The inputs to this model were estimated hypothetical uncontrolled flow at Kidatu, observed flow at Kilombero and the observed intervening rainfall. The annual maximum floods of this estimated time series were plotted against a similar time series obtained from step (a) above, as shown in Figure 3. The observed annual maximum floods time series at Stiegler's Gorge prior to impoundment at Kidatu (i.e. before 1976) was plotted in the same figure in an effort to depict the annual maximum flow trend at Stiegler's Gorge before impoundment at Kidatu.

From Figure 3, it can be seen that the impact of impoundment is minimal at Stiegler's Gorge. This could be due to the high augmentation of flows at Stiegler's Gorge by the uncontrolled flows from Kilombero, which stands at 520 m^3/s on the average as compared to 160 m^3/s at Kidatu. The annual expected maximum floods of if there were no impoundments do not exceed 25 percent of the maximum floods being experience after the impoundments and even at certain years being lower than experienced maximum floods. Flow from the ungauged Luwegu subbasin also contributes very substantially to the flow at Stiegler's Gorge.

Summary and Conclusion

One of the three main tributaries to the Rufiji River, the Great Ruaha River, was impounded in mid-1980, while the impoundment at Kidatu was in 1976. Hypothetical uncontrolled flow, i.e., flow that would have occurred had there been no impoundment at Mtera and Kidatu was estimated from 1980 to 1993 for the Mtera Reservoir and for the Kidatu Reservoir the period was between 1975 and 1993, inclusive.

As suggested in the method section of this paper, percent error in peak criterion is often not successful in most hydrological applications and this was no exception in this study. For instance, the maximum recorded discharge at Stiegler's Gorge was a little over 6,200 m^3/s and the models predicted an average percent error in peak of 35 percent, implying the models could predict this flow within 6,200 ± 2,170 m^3/s. This does not look good in comparison of observed against estimated; however, there is some jus-

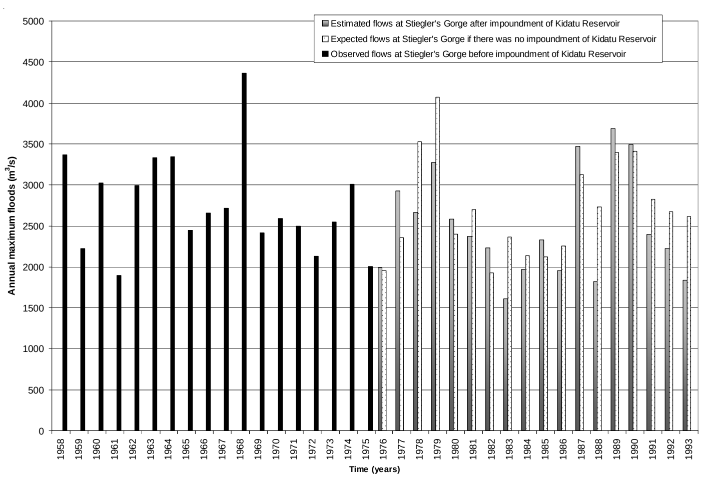

Figure 3. Comparison of annual maximum floods at Stiegler's Gorge with impoundment and assuming no impoundment at Mtera and Kidatu

tification if comparisons are made from model estimates of with and without dam scenarios, and this is what this paper has tried to do (see Figure 3). Improvement of this percent error in peak might be possible if non-linear models are employed and/or tested.

In times of high flows into the Mtera-Kidatu Reservoir System, the spillway gates are opened to induce excess floods downstream of the system. However, these floods contribute marginally to the flows at Stiegler's Gorge when compared to the flows from the other sub-basins.

Hence, the impact of the impoundment of the Great Ruaha River sub-basin of the Rufiji River Basin is minimal at Stiegler's Gorge in terms of the annual maximum floods. This is because flows from Kilombero and Luwegu sub-basins, although they constitute a smaller area in comparison with the Great Ruaha sub-basin, contribute more flow to the Rufiji River at Stiegler's Gorge. Hence, it has been concluded that Mtera-Kidatu Reservoir System has no significant impact on the annual maximum floods at Stiegler's Gorge, and hence the reservoir system plays no significant role in the frequent occurrence of flooding at the Rufiji floodplains in Tanzania.

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