Development of an Effective Operation of Pequenos Libombos Dam in the Context of Climate Change in Mozambique

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ABSTRACT

The way that the operation of Pequenos Libombos Dam are doing, becomes in a challenge from the point of view of water resources management as well as disaster management, this because is necessary to keep the infrastructure and the valley downstream safe, and at same time to maintain the higher level in reservoir to ensure the socio-economic objectives for which the dam was built. The effects of climate change on the basin are increasing the droughts and the heavy rainfall in short time. This study will propose an effective dam operation based on inflow forecast using an Integrate Flood Analysis System (IFAS) to determining a preliminary release discharge. The Umbeluzi River Basin with 5 640 km^2 have a short travel flood, less than one day, therefore a correlation between rainfall and inflow of passed flood events proposed by Miyamoto *et al.*, 2004 was used to get the equation for preliminary release based on inflow forecast from IFAS model. The flood risk was obtained applying a Rainfall Runoff Inundation (RRI) model with the results of the preliminarily dischargers as a boundary conditions to verifying the inundation area downstream the Pequenos Libombos Dam.

Keywords: Inflow forecast, IFAS, Effective dam operation, Correlation, RRI, Inundation risk

INTRODUCTION

Mozambique is a country situated in southern part of Africa continent with total area about 800.000 km^2, inland limited by Tanzania, Malawi, Zambia, Zimbabwe, Swaziland and South Africa, on the east side by Indian Ocean. The Umbeluzi River Basin is an international basin, born in Swaziland where it has two main tributaries, the Black M'buluzi and White M'buluzi rivers, and enters in Mozambique at Goba border. With the elongated shape as shown in Figure 1, the basin is shared by three countries, Swaziland, Mozambique and a small portion in South Africa, according to Maluvane, *Registos nas Bacias do Umbeluzi, Incomati e Limpopo, Maputo* (2000). It has a surface of 5 640 km^2 of which 40% located downstream is in Mozambique. The remaining area are distributed by 58% in Swaziland and considerable small portion of 2% in South Africa. The Mozambican part of the basin is located entirely in the Maputo province and the tributaries are the Calichane River and the Movene River, respectively upstream and downstream of Pequenos Libombos Dam (BPL).

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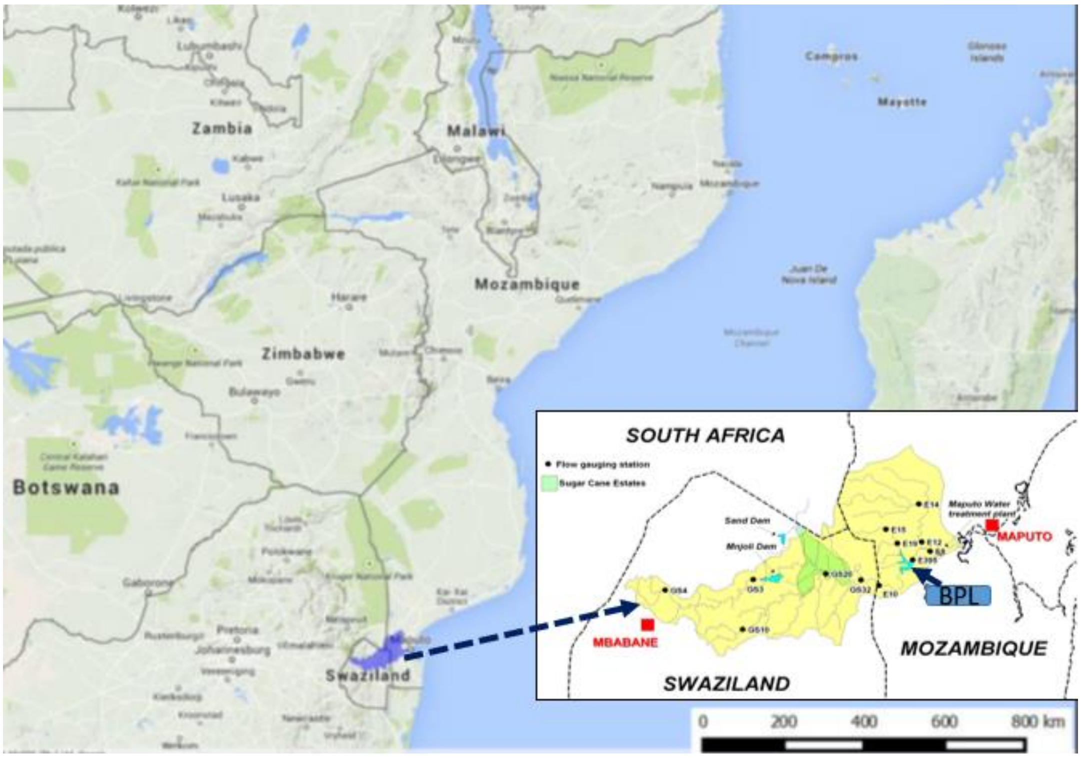

Figure 1: Geographical location of Mozambique, Umbeluzi River Basin and Pequenos Libombos Dam (Figure adapted from Future Water, 2014 and UGBU Activities Report)

In the Umbeluzi River Basin two important infrastructures were built. Mnjoli Dam in Swaziland, built in the end of the 70's to irrigate the extension fields of sugar cane, and in Mozambican part, located abound 40 km of Maputo city, was built the Pequenos libombos Dam, an infrastructure built with main reason of water supply Maputo city and surrounding areas. Supply industry, irrigation with maximum estimation area of 3 500 hectares, power generation with capacity of 1.72 MW, fishing and tourism, are other purpose that makes the dam a multipurpose infrastructure.

Figure 2: Normal spillway and emergency spillway of the BPL (view from downstream)

The inundation area of the reservoir is 38 km^2 and total storage capacity at crest level (47 m) is 400 Million m^3. The normal discharge to downstream of the dam is about 4.45 m^3/s, made through the bottom outlet to river maintenance and other uses of the dam. The spillway is controlled by seven radial gates with total capacity of discharge 5 600 m^3/s.

The altitude is one of the factors that contributes significantly to the variability of the climate in the Umbeluzi River Basin and according to Lopes (2011), the annual average temperature is around 24 ºC, with the peak of the cold occurring in June and July and the peak of heat in the months of January and February. The annual average precipitation, also influenced by altitude, is 752 mm. Umbeluzi River Basin is affecting by Climate Change phenomenon. According with the Fifth Assessment Report (2013) of IPCC for Southern Africa, for temperature and precipitation patterns, cited also in Water Allocation Models for the Umbeluzi River Basin, Mozambique (December 2014), the precipitation patterns will decrease in abound 10% and the temperature will increase abound 3 ºC, considering RCP 6.0 – (Representative Concentration Pathways). These changes in temperature and precipitation reveals an urgent need for adaptation in the sense that increasing temperature will cause more evaporation, more demand for urban water supply and other uses in the basin. The report Climate Change Adaptation in SADC - A Strategy for the Water Sector (2011), some orientation are recommend to the region countries to follow in which the present study of improvement of the operation of the BPL fits.

METHODOLOGY

The methodology followed for this study of improvement of the operation of the Pequenos Libombos Dam, follow three steps:

(i) ***inflow forecasting:*** an Integrate Flood Analysis System (IFAS) model was used for inflow forecasting, this model was special design to flood forecasting in cases of lack of hydrological data. According to the IFAS manual, the model consists of three tanks vertically distributed, which are fill by the effect of the precipitation that falls on the soil surface. The precipitation that doesn't infiltrate, flows through the river course up to the reservoir. For the present study, 2 Layer Tank Model (Surface Tank and Aquifer Tank) was used.

(ii) ***effective dam operation:*** for the size of Umbeluzi River Basin, where is located BPL, flood travel is short, less than one day, a correlation adopted was between total volume inflow and corresponding total rainfall ($V = f(R)$). The equation obtained from this correlation will give the preliminarily discharge, method proposed by Miyamoto *et al.*, 2004.

(iii) ***flood risk:*** the flood risk area was obtained applying a Rainfall Runoff Inundation (RRI) model with the results of the preliminarily discharge as a boundary conditions to verifying the inundation downstream caused by the discharge made from BPL and by the rainfall. RRI model is a two dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously (Sayama *et al.*, 2002).

DATA AVAILABILITY AND LIMITATIONS

For this study, the hydrological data of the basin and the water balance of the Reservoir was necessary to curry out the preliminary discharge. For carrying out this study, 26 years of water balance of the Reservoir (1990-2015) was available and daily data of 23 Precipitation stations (some of them represented on the Figure 1), 26 Water Level stations and 18 Discharge stations. The data are collected by ARA-Sul through the Umbeluzi River Basin Management Unit (UGBU) and sent to central management, National Directorate for Water Resource Management. Due to some limitations in terms of time interval of the available observed data (Umbeluzi River Basin has the total area of abound 5 460 km^2, consequently a <u>short lead time)</u>, hourly data from Global Satellite Mapping of Precipitation (GSMaP) was also available for the present study. In order to have a practical results of an effective dam operation, the hourly data is necessary, but the time interval of availability data in UGBU was daily. To fill this gap and analyze the dam operation, hourly GSMaP rainfall data was tested. However, the results of the simulation models using satellite data wasn't good to proceed the study. On a comparison between accumulated ground gauge rainfall and GSMaP Rainfall, there's some stations with good correlation but others with big differences special in a daily comparison. The comparison was made by simple method using the following equation one (Eq. 1). Considering the IFAS simulation for the two rainfall products, the shape of the hydrographs for ground gauge is almost the same compare with observed. In conclusion, the GSMaP was not reliable to use in this study.

$$Ground = GSMaP * Coefficient \quad \text{Eq. 1}$$

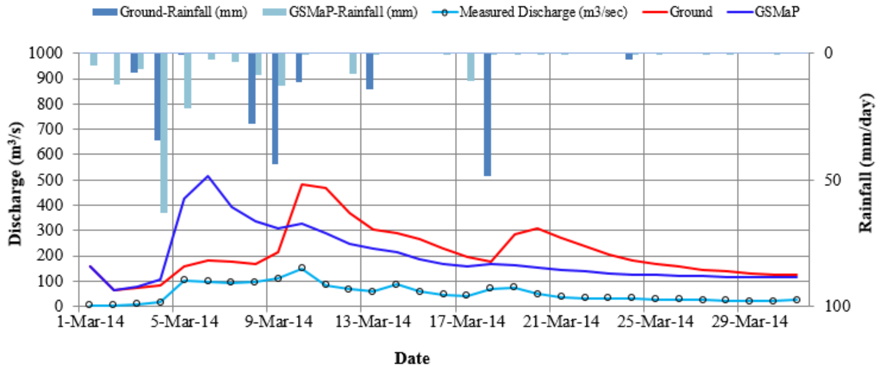

Figure 3: IFAS simulation results from comparison of GSMaP and Gauge Rainfall on March 2014

In additional, considering the existence of the Mnjoli Dam with 153 M m^3 of storage capacity upstream of Pequenos Libombos Dam in Swaziland and the effects that this infrastructure on the event of 2014, was assume the condition of: (i) full storage of Mnjoli Dam; and (ii) empty storage of Mnjoli Dam.

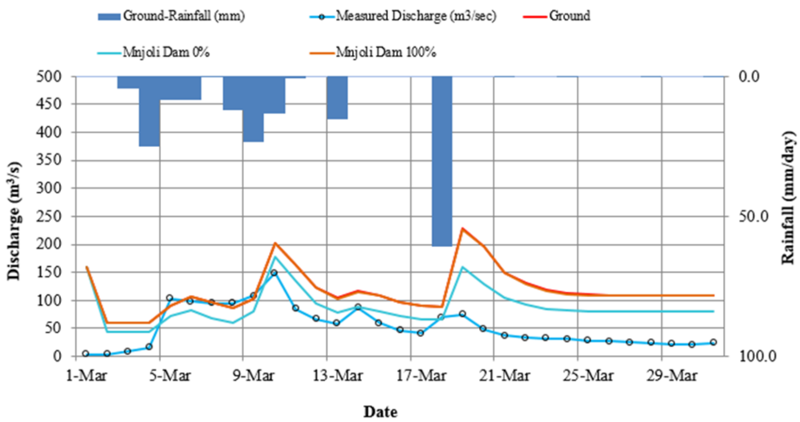

Figure 4: Effects of Mnjoli Dam on 2014 event

The IFAS simulation results for this events, shows that this dam didn't have significant effects on 2014 event simulated, as shows on the Figure 4. The figure above, represent the hydrographs for the assumption for this situations: (i) Assuming the full storage condition of the Mnjoli dam, that means upstream there's no dam, the results should be equal to the simulation considering ground gauge rainfall. As shows on the Figure 4, the results for this two conditions were almost the same; (ii) Assuming the empty storage condition of the Mnjoli dam, that means the Mnjoli dam absorb the inflow upstream the dam and the results on the discharge point should be lower than the first case.

RESULTS AND DISCUSSION

In order to achieve an effective dam operation, IFAS model was used to get the inflow discharge. The calibration process of the model was done for the 2000 flood event changing of parameters until reached discharge values close with observed. After calibration process, the parameter of the best case was used to get inflow forecast discharge as it shows on figure 4. Based on the past events, with the correlation between inflow and rainfall (short lead time for Umbeluzi River Basin) was obtained the equation for preliminary discharge. According to the limitation of the hourly observed data, on the correlation between inflow and rainfall observed, was included the correlation between inflow forecast and rainfall results of IFAS simulation (Figures 5 and 6) to get equation for hourly discharge.

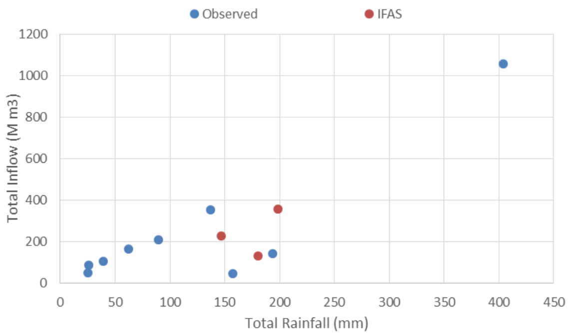

Figure 5: Past event observed and IFAS simulated event

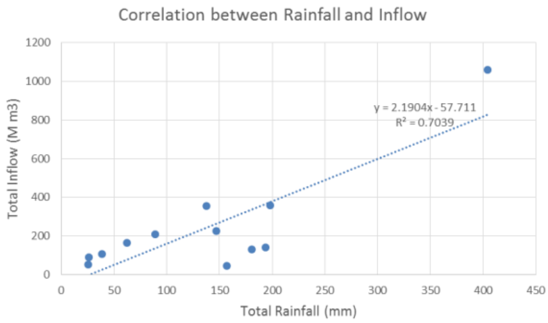

Figure 6: Correlation between inflow and rainfall (observed and simulated)

Therefore, the outflow was obtained using the following equation two (Eq. 2):

$$Qout = y(x) = y(Qin) = 2.1904Qin - 57.711 \quad \text{Eq. 2}$$

Using the Eq. 2, the preliminary discharge was simulated using a excel sheet for four situations and considering the minimum discharge for urban water supply, industry, irrigation and environment of 4.45 m^3/s: (i) assuming lower condition of storage of the dam; (ii) assuming the real volume of the reservoir for the event in analyze; (iii) assuming the flood control curve respected on the beginning of the event; and (iv) assuming the full storage of reservoir on the beginning of the event. For the cases (i), (ii) and (iii) using this methodology was possible to control the peak flood, making smoothly discharges to downstream without using the emergency spillway and finish the event with dam totally full, 384 M m^3 (The Figure 7 represents the case (ii)). For the case (iv), the dam will exceed the maximum level and the breach will occur due to the overtopping of BPL or the discharge necessary to control the inflow will cause several damage downstream the valley.

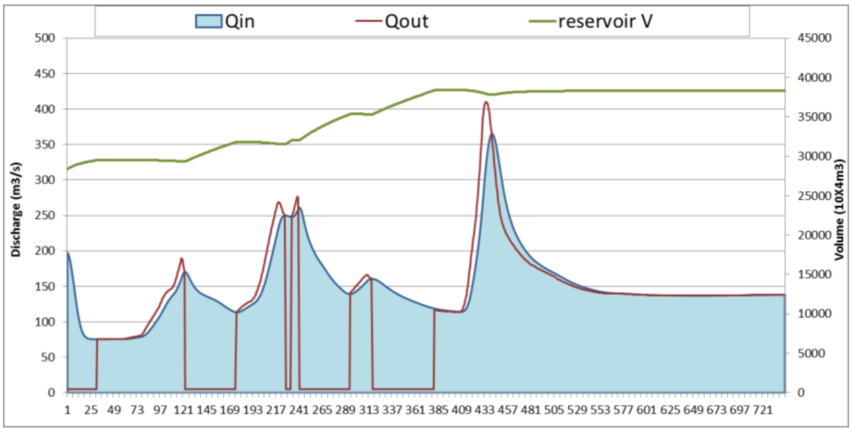

Figure 7: Operation of reservoir assuming the real volume of the reservoir for the event in analyze (309 M m^3)

One of the goals of the Pequenos Libombos Dam is flood control. Therefore, the discharge from the dam should be done smoothly in order to reduce damage downstream. Keeping high level on the dam to ensure security water supply during dry season, contrasts with the necessity of maintain the level of the dam in order to flood control. For the inundation risk area was used the Rainfall Runoff Inundation

(RRI) model with the results of the preliminarily dischargers as a boundary conditions to verifying the effects of discharge downstream of BPL. The calibration process of the model was done changing of parameters until reached discharge values close with observed. Applying the parameters of the best case to the event of March 2014, was possible to obtain the inundation area (Figure 8) and was clear the effects in flood control of the dam in comparison with the inundation area for the case of inexistence of BPL (Figure 9).

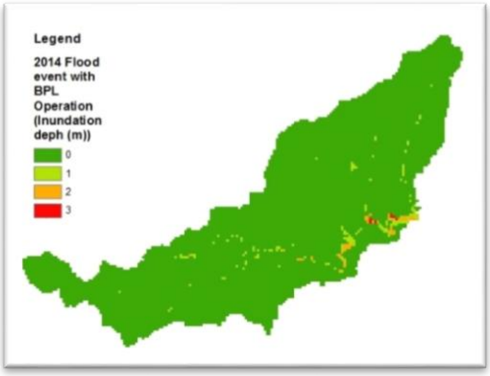

Figure 8: Inundation Area with BPL operation

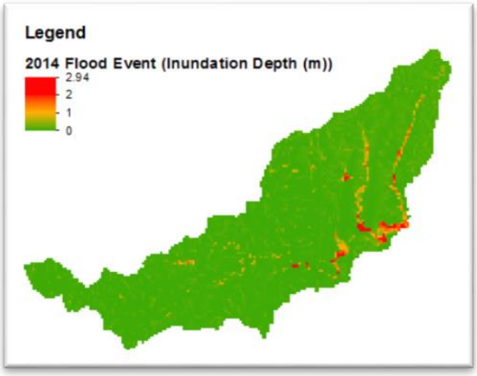

Figure 9: Inundation Area without BPL operation

RECOMMENDATION

The following recommendations are made in order to improve the operation of the infrastructures in the country, special to Pequenos Libombos Dam, aligned with the recommendations of SADC to climate change adaptation. To achieve on better results of an effective dam operation of BPL, which the travel flood time of the basin is short, hourly data should be available. Since there's a telemetric system installed on the basin, is recommended the rehabilitation of this system for hourly data collection. Improvement of spatial distribution of rain gauge, increasing the number of the stations will improve the accuracy of the model results. A new dam in Movene River, tributary of Umbeluzi River downstream of BPL will improve the flood control capacity on the basin and at same time increase the levels of safety in the water supply whose demand tends to increase and the availability tends to decrease. Being Umbeluzi River Basin transboundary, the existence of a platform to share hydrological information of the basin between the counties will help the states on better manage the water resources and reduce flood damages.

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REFERENCES

1. CONSULTEC & SWECO, 2010, Regras de Operação das Albufeiras de Massingir, Corumana e Pequenos Libombos.
2. Future Water, 2014, Water Allocation Models for the Umbeluzi River Basin, Mozambique.
3. Maluvane, 2000, Registos nas Bacias do Umbeluzi, Incomati e Limpopo, Maputo.
4. Miyamoto M., Akiba M., Toya H., Yamada T., 2004, Study on Determination Method of Amount of Dam Discharge According to the Runoff Characteristics, Proceedings of 2ndAPHW, pp.249-260.
5. Sayama T., Rainfall Runoff Inundation (RRI) Model user's Manuals (Ver 1.4.2).