DEVELOPMENT OF COMPREHENSIVE RESERVOIR OPERATION FOR FLOOD WITH INCORPORATED INFLOW FROM CASCADED SMALL TANKS TO PAVATKULAM RESERVOIR, SRI LANKA

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ABSTRACT

In the ancient time tank cascaded system was constructed in dry zone of Sri Lanka to ensure the water availability for agriculture. In this area upper catchments of every reservoir cascaded through small tanks. So the small tanks are influencing the inflow of reservoir in flood time due to natural breaching and artificial cut opening of small tanks. In this study, the small tank impact on reservoir inflow is calculated based on average basin rainfall and effective reservoir operation based on inflow forecasting for Pavatkulam reservoir is prepared. The small tank impact on reservoir inflow is suggested based on past records of daily rainfall and water level of reservoir. And the concept of effective reservoir operation based on inflow forecast and releasing preliminary release before flood takes peak based on catchment average rainfall. To do this effective operation the hourly rainfall is necessary, but the particular river basin poorly gauged with measuring daily rainfall and reservoir water level. Therefore applicability of satellite rainfall in this river basin was analyzed and 3B42RT rainfall selected for analysis. To do the inflow forecasting the Integrated Flood Analysis System (IFAS) is used with 3B42RT rainfall. Then by using Rainfall-Runoff-Inundation (RRI) model the flood inundation area was compared between suggested reservoir operation and without suggested operation. The suggested method for update the breaching scenario is stake holder's corporation.

Keywords: Tank Cascaded System, Correlation, inflow forecast, small tank impact, inundation area

INTRODUCTION

As per the average annual rainfall the island was divided into three zones, such as dry zone, intermediate zone and wet zone. Dry zone, the average rainfall between 1200 to 2000 mm, the 80 % of rainfall happen from October to January. So this period the area was under flooding condition. At the same time the annual average evaporation loss between 1700 mm to 1900 mm (Panabokke et al., 2002).The combination of the eight month period soil get moisture deficit, due to this condition under drought. The wide area of the island falls under this zone, such as major part of southeast, east and northern.

In ancient time manmade Tank Cascaded System (TCS) was constructed in dry zone to ensure the water for agriculture and maintained by society. In this study I took flood study of the major reservoir called Pavatkulam in Vavuniya district in Northern Province. The Pavatkulam scheme located at sub basin of Malwathu Oya river basin, which is the second largest river in Sri Lanka, having catchment area of 3,246 sq. Km. In the upper catchment of this river cascaded by more than 1500 small/medium tanks and two major reservoirs. The major reservoirs are namely Pavatkulam and Nachchaduwa. In this river, these major reservoirs only having the flood controlling facility. Other schemes had only the spill way, if unexpected flood came then the farmer's organization or respective department will artificially cut open the emergency cut opening to safeguard the bund, downstream people and assets or naturally breaching. In year 2010/2011 and 2014, the rainfall intensity was high and due to breaching& artificial cut opening of small tanks and improper operation of reservoirs the Malwathu Oya river breached and flood damaged occurred in the entire river basin.

In the upper catchment of Pavatkulam nearly 147 water bodies are located. As per the records from Agrarian Development Department, 97 medium/small tanks and others small ponds. The total capacity

of medium/small tanks in upper catchment is 23.8 MCM, but the total capacity of Pavatkulam reservoir is 33.30 MCM.

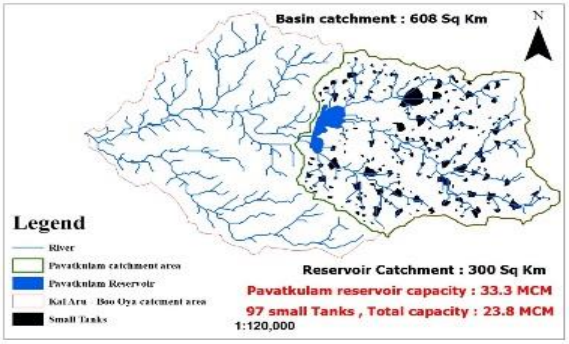


Figure 1 spatial distribution of small tanks in Pavatkulam catchment.

Due to the high intensity of rainfall in 1957, the medium tank called Iratperiyakulam and several small tanks were breached in the upper catchment of Pavatkulam reservoir, due to that Pavatkulam reservoir was breached (S.Arumugam et al.,1969). Due to the La Nina effect, the intensity of rainfall has increased in this recent three to seven years. So the reservoir getting full condition within 15 days. At the same time, the department and Farmers Organizations try to keep water at maximum level to do the maximum acreage crop cultivation in minor cultivation period. When the rainy season is continued in dam full condition, then department suddenly operate the radial gates to safeguard the reservoir, so due to this unplanned reservoir operation is causing floods in downstream and damaging crops.

In 2010/2011 rainy season, nearly three month period, the reservoir operation was done. The main river Malwathu Oya breached and several infrastructure washed away in February 2011 and 2014 due to heavy rainfall and unplanned reservoir operation in upper catchment. At that time the government realized the necessity of proper reservoir operation rule for flood control.

In this period, the department has realized the necessity of hydrological model application for inflow forecasting to do the better reservoir operation and small tank impacts on reservoir inflow during flood time. Therefore as per the previous experience in my country I realize and taken the Pavatkulam reservoir for my thesis study. The objective of my thesis are as follows

1. Evaluate the impacts of small tanks on the Pavatkulam reservoir inflow during flood events
2. Inflow forecasting during flood time.
3. Development of effective reservoir operation for floods.
4. Assessment of Inundation area for floods.

THEORY AND METHODOLOGY

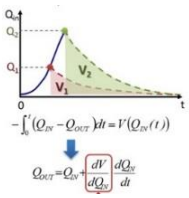
In this study the following steps was carried out

1. Impact of small tanks
2. Inflow forecasting by IFAS
3. Effective reservoir operation Small tank management scenario
4. Assessment of Inundation area

Analysis of Small Tanks Impact

As per the climatic condition of dry zone of Sri Lanka received rainfall from October to February. And in end of May all the small Tank will be come under empty. So in this study the small tank impact calculated based on catchment average rainfall. Water level variation and inflow to the reservoir for each years were analyzed and small/medium tank full condition and major reservoir full conditions were fixed for every years.

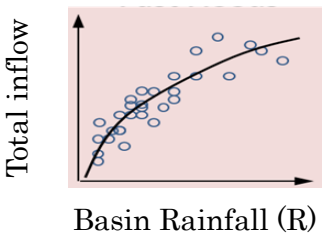
Effective reservoir Operation.



(Miyamoto *et al*, 2004)

Inflow forecasting by IFAS.

The main objective of this study is preparation of suitable reservoir operation rule for Pavatkulam reservoir. To achieve this target the hourly inflow of Pavatkulam scheme is produced by the Integrated Flood Analysis System model after small tank full condition. So the basin has the daily measurement of rainfall and water level. So applicability of satellite rainfall analyzed and IFAS model calibrated and validated with satellite rainfall.



Basin rainfall Vs. Total inflow

Out flow (Q_{out}) of the reservoir can be written as

$$Qout = Qin + \frac{dv}{dt} \qquad (1)$$

Where, Qin : inflow to reservoir (m^3/s), Qout : out flow(m^3/s)

The correlation or function between volume of inflow and basin average rainfall can be built by using past flood events daily data and IFAS simulated hourly hydrograph. If the correlation is built by using that the total volume of inflow can be calculated in terms of basin average rainfall. Then by using the predicted inflow the reservoir preliminary release can be made before flood inflow reach to reservoir and also at the end of season the reservoir capacity can be maintained at full.

Small tank management.

The breaching tank water inflow to the reservoir measurement is not available. Therefore, in this study the inflow hydrograph due to breached tank water is calculated by introducing log normal distribution. The probability density function of the lognormal distribution with parameters μ and σ is as follows.

$$f(x) = \frac{1}{\sqrt{2\pi\sigma x}} \exp\left(-\frac{[\ln(x)-\mu]^2}{2\sigma^2}\right) \qquad (2)$$

Where, μ : mean, σ : standard deviation.

Assessment of Inundation Area

Inundation area is one of the tool to compare the effective reservoir operation. In this study to evaluate the effective reservoir operation Rainfall-Runoff-Inundation (RRI) model ver 1.4.2 is used. RRI model is a two dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously (Sayama et al., 2002).

DATA

In this river basin, the department maintaining three rain gauge stations and one water level gauge at reservoir. They used to measure rainfall and water level on daily basis. In this study the rainfall and water level records from 1993 to 2014 were used.

RESULTS AND DISCUSSION

Small tank Impacts

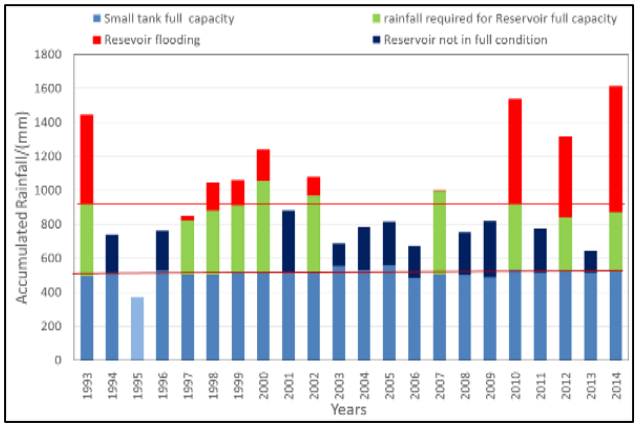


Figure 2 Break down of Basin Rainfall

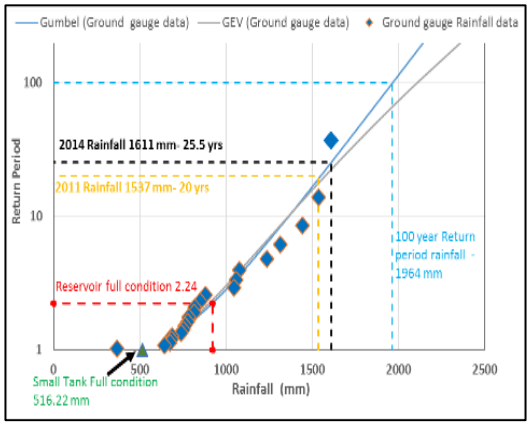


Figure 3 frequency analysis

In this study the small tank impact was suggested based on the catchment average rainfall for the Pavatkulam scheme. According to the analysis, the small tanks became full condition when the accumulated basin rainfall from June reaches to 522.16 mm. As per the frequency analysis it was indicated that small tanks got full capacity annually and the return period for reservoir full condition is 2.4 years. These analysis will help to monitor and evaluate of reservoir on flood. Also it will help the officer who is physically operating this scheme.

Inflow forecasting

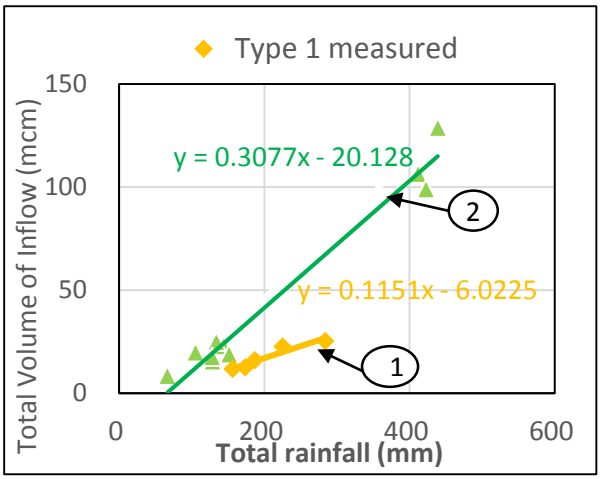


Figure 4 basin rainfall Vs. Inflow

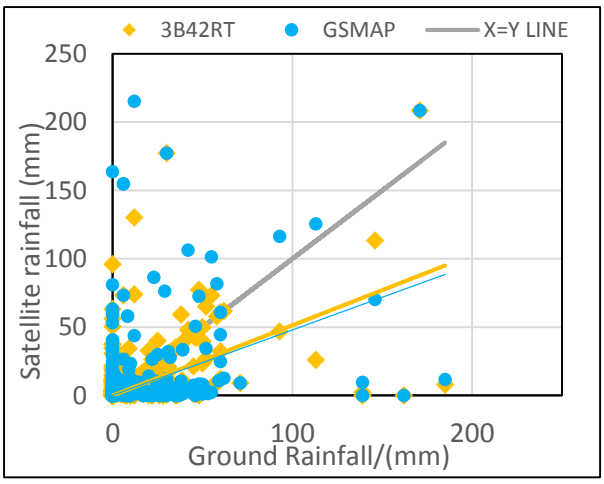


Figure 5 Comparison of Satellite Rainfall

In order to find the flood events for calibration and validation, the accumulated rainfall and total inflow was calculated for past flood events by using measured available daily data. Then the accumulated rainfall against total inflow was plotted and there are two possible correlation was found and built. So in this area by considering the seasonal rainfall pattern the main purposes of the tanks/reservoir is to store the water at maximum level and the flood control is secondary. So the IFAS calibration and validation to be done based on first correlation flood events and the small tanks breaching scenario to be considered separately. Because if the inflow simulation done based on second correlation flood event then the reservoir operation also considered based on that, but actual inflow may be on first correlation. So finally at end of the flood event the reservoir cannot be maintained at full capacity.

To confirm the applicability of the satellite rainfall, the comparison of daily satellite rainfalls of GSMaP NRT and 3B42RT with ground rainfall was done for different years flood event. The comparison shown in figure 4-5, from the comparison the 3B42RT rainfall is agree to ground gauged daily rainfall. So the 3B42RT rainfall taken for the simulations. Then IFAS model calibrated and validated. The model efficiency is calculated based on Nash_Sutcliffe and found E= 0.803. So this model can be used for inflow forecasting

Reservoir Operation

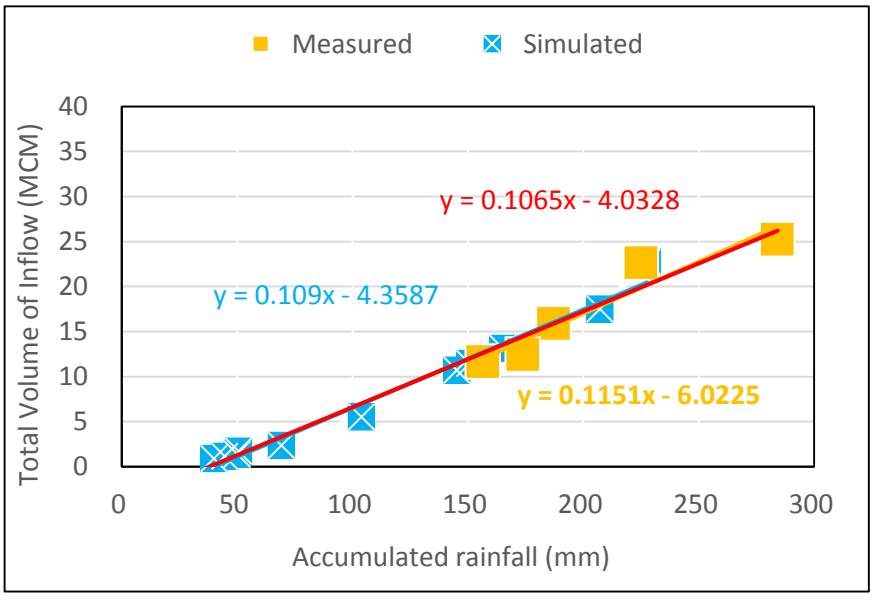


Figure 6 correlation between Basin rainfall and Inflow

For the effective reservoir operation, the combined correlation was built between accumulated basin rainfall& inflow volume to the reservoir based on IFAS simulated hourly results and correlation 2 of measured data daily. The combined correlation is shown in figure 6.

At present, the reservoirs in this area operated based on real time water level variation of reservoir. The reservoir could operate effectively when reservoir bellows the full capacity. Main challenge would be the farmers in the region against to release water below full capacity because the reservoir located in the dry zone area and reservoir not get full capacity annually. Therefore reservoir operation started at reservoir full capacity. In this study reservoir operation suggested based on the inflow forecasting, the flood release suggested based on average reservoir upper catchment rainfall. This reservoir operation reduce the peak flood flow flow(normal flooding by 170 m^3/s and breaching scenario by 346 m^3/s) in Kal Aru Boo Oya River and also reduce peak flow in Malwathu Oya river basin.
The breaching scenario also analyzed in this study for Pavatkulam scheme, the worst case was taken and proposed dam operation was applied based on expected inflow. Found the proposed reservoir operation kept the reservoir capacity below the High Flood Level (HFL) and also reduced the peak flow for the worst case in 2011 January. The effect of reservoir operation was analyzed by the application of Rainfall Runoff Inundation (RRI) model and found the suggested reservoir operation reduce the peak inundation depth(normal flooding by 0.91 m and breaching scenario by 1.66 m) as well as peak inundation area.

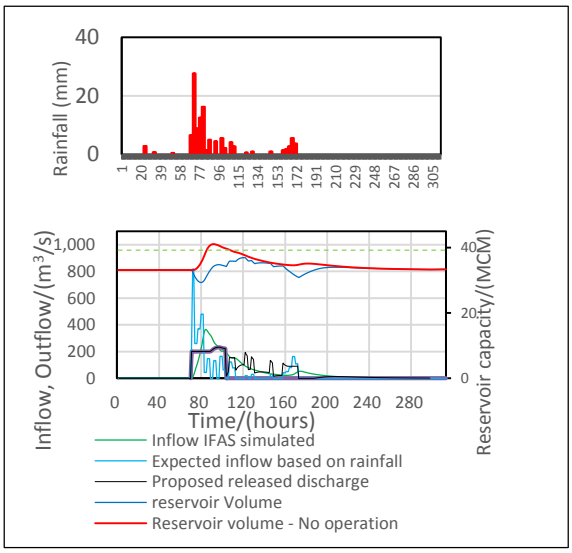


Figure 7 Reservoir operation in 2011

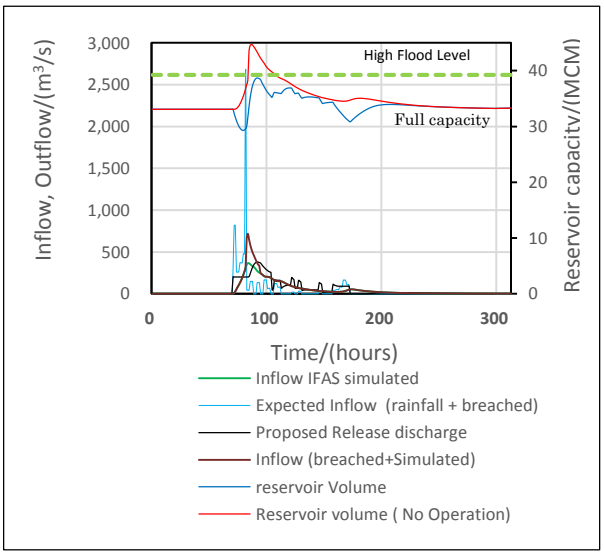


Figure 8 Reservoir operation with breaching scenario

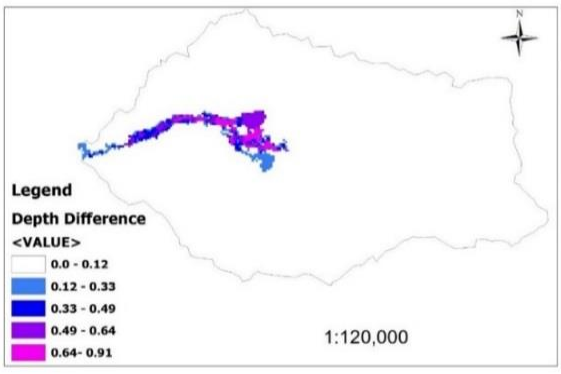


Figure 9 effect of Reservoir operation in 2011

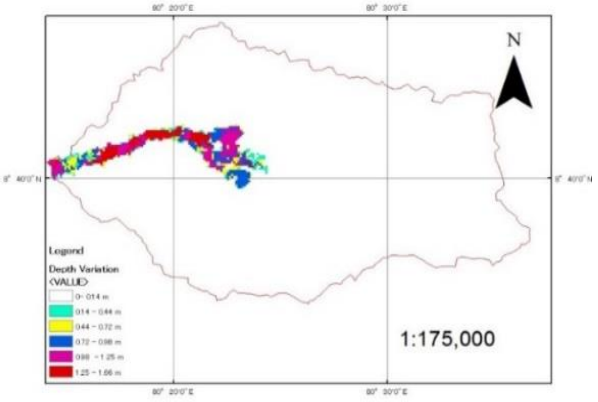


Figure 10 effect of Reservoir operation with breaching scenario

RECOMMENDATION

In this study, the small tank impact on reservoir inflow is calculated based on average basin rainfall and effective reservoir operation based on inflow forecasting for Pavatkulam reservoir is prepared. In addition to that the following suitable recommendation were found to operate the reservoir in efficient way.

1. At present the water level measured at daily basis for the efficient reservoir operation it should be measured at hourly basis because the flood traveling time is less than 24 hours.
2. In this basin flood flow traveling to reservoir is less than 24 hours. Delay of delivery of 3B42RT is six hours. The first hour rainfall will be obtained after nine hours. Therefore it is impossible to operate the reservoir with the 3B42RT rainfall. So at least, the existing rainfall station to be modernized to measure hourly rainfall.
3. The river discharge is calculated from the old H-V correlation of reservoir. So it should be updated for current conditions.
4. Bellow the Pavatkulam Reservoir the river channel capacity to be increased at least up to 200m^3/s in terms of out flow.
5. Regular maintenance is necessary for small/medium tanks to avoid natural breaching.
6. The small tank improvements in upper catchment like raising the spill crest will result in average accumulated rainfall required for small tankful condition. But the same calibrated hydrological model can be used after small tank full condition.
7. Using this calibrated model the flow contributed to Main River by this sub river basin can be simulated and informed to river management office for further action.
8. Currently due to the lack of small tank individual data (spill crest length, water level and discharge) the small tank impacts in inflow is considered overall. But In future new hydrological model can be introduced to consider the small tanks impacts individually to the reservoir.

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