EFFECTIVE DAM OPERATION METHOD BASED ON INFLOW FORECASTING FOR SENANAYAKA SAMUDRA RESERVOIR, SRI LANKA

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ABSTRACT

The existing real time dam operation rules depend mostly on the prevailing inflow and the storage capacity of the reservoirs. Such rules are mostly focused on dam safety and often non-effective regarding flood control at downstream. When failure to achieve effective reservoir flood operation, it causes dam flooding which is rapid and uncontrolled release of reservoir excessive water. In this thesis, effective dam operation method based on inflow forecasting for Senanayaka Samudra reservoir is suggested. The concept is to forecast the reservoir inflow and to release preliminary outflow before flood takes place. The size of the basin is about 1,000 km^2 and the flood travelling time of the reservoir basin is less than 24 hours. Therefore, hourly inflow forecast is necessary for effective dam operation. However, the basin is poorly gauged consisting daily rainfall and daily reservoir inflow with only one event of hourly reservoir inflow data. Therefore, the Integrated Flood Analysis System (IFAS) is used to analysis different satellite rainfall data sources including hourly GSMaP rainfall data. The correlations between reservoir inflow volume and basin rainfall are developed by using hourly satellite rainfall along with IFAS inflow results and daily ground rainfall with corresponding daily measured reservoir inflow data based on past events. Dam operations based on inflow forecasting by these correlations and existing real time operation are then compared. It is shown that the early flood release, peak outflow reduction and more gate controlled discharge than uncontrolled spillover can be achieved with the dam operations based on inflow forecasting. The suggestions made in this study on effective dam operation based on inflow forecasting are expected to be useful in flood management in Senanayaka Samudra reservoir.

INTRODUCTION

Flood is the most recurring natural disaster in Sri Lanka which causes negative impacts on human life and also loss of agriculture production and damage on infrastructure such as houses and roads. Due to the high intensity of rainfall during the northeast and southwest monsoons, most of the reservoir's capacity reach to their full supply level (FSL) and start to spill the exceed water either by naturally or by gate operations.

Failure to achieve effective reservoir flood operations causes dam flooding which is the rapid and uncontrolled release of reservoir volume. Dam flood causes severe flooding while accumulating stagnant water at downstream. This situation worsens when downstream rivers and low lands are already occupied by flowing and stagnant water respectively due to the prevailing rainfall associated in these areas by leading to a prolonged flooding. (Diman et al, 2012)

The existing operation rules of reservoirs depends mostly on the inflow and the available storage capacity in the reservoirs. Such rules are mostly focused on dam safety and often non-effective regarding flood management at downstream. With insufficient storage capacity in the reservoir, the emergency operating rules of the dams force the operator to release water through the gated spillways. These emergency rules of the reservoir are often in contradiction with the effective operation for the reduction of the peak flow downstream.

Reservoir inflow forecasting helps to avoid these sort of unfavorable situations through the comparison of available reservoir capacity with the future inflow. It is possible to have the full reservoir capacity at the end of the reservoir flood operation by opening the spill gates before the flood peak increases the retained reservoir capacity and limit the water releases during the peak discharge when probable inflow exceeds the available storage capacity. (Jordan et al, 2012)

The Irrigation Department (ID) has the main responsibility of hydrology and flood forecasting in Sri Lanka. There are 72 Major reservoirs & 160 medium tanks, maintained by the department. Reservoir flood control is done by respective Divisional Irrigation Engineer and his staff. Normally standing orders for each reservoir which provides operational rules to be complied with during the monsoon rainy seasons, are available. These operational rules mostly focus towards dam safety rather than effective flood management and decisions are made based on real time inflow, reservoir water level variations and prevailing rainfall. The department so far does not use any sort of inflow forecasting techniques in reservoir flood management except the real time operations. The ID realized the impotency of the effective dam operations after their experience during the year 2011 flood.

The water level of Senanayaka Samudra reservoir (also called Inginiyagala reservoir) which is studied in this theses, reached to its highest level and all 6 spill gates were opened during the 2nd February 2011. As the water level continued to rise, overflow through spill commenced in next day. Senanayaka Samudra reservoir is the largest reservoir in the country and this water outflow caused prolonged flooding at downstream low lying area in the Ampara and Baticaloa Districts.

Therefore, the specific objectives of this study are as follows.

1. To develop an effective dam operation method based on inflow forecasting.
2. Suggestions to enhance the existing set of operation rules.

This study can assist the ID, to perform the dam operations effectively.

THEORY AND METHODOLOGY

The Senanayaka Samudra basin area is about 1,000 km2. The flood travelling time of Senanayaka Samudra basin is less than 24 hours. Therefore, hourly rainfall data are essential for analyzing the effective dam operation concept based on inflow forecasting when the basin flood travelling time is shorter than 24 hours. However, within the study area, only daily ground rainfall data are available. Therefore, satellite rainfall data from different sources such that GSMaP are to be used in this study. By taking these facts into consideration, IFAS model is selected to analyze different type of satellite rainfall data.

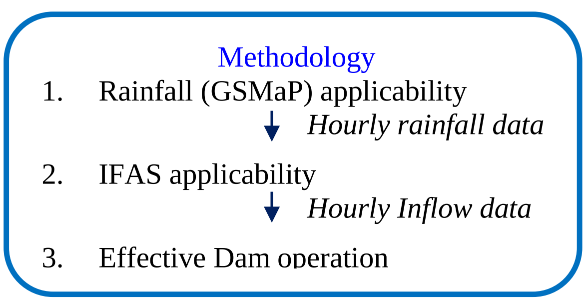

Figure 1 Schematic diagram for Methodology

As shown in **Figure 1**, applicability of satellite rainfall (GSMaP) as hourly rainfall input for the basin is checked at first. Then the applicability of IFAS model for Senanayaka Samudra reservoir basin is checked by using the available hourly reservoir inflow data measured during the year 2011 flood. Then the correlations necessary for reservoir inflow forecasting based on reservoir basin rainfall are built. In this case two correlations are built by using GSMaP hourly rainfall and relevant IFAS hourly inflow results and daily ground observed rainfall and relevant daily ground observed reservoir inflows. With the help of these correlations, effective dam operation method based on inflow forecasting is developed. By this effective dam operation peak reservoir outflow is reduced by releasing the preliminary discharge before inflow reached to the reservoir in a way that reservoir capacity is maintained at its full supply level at the end of the dam operation.

In the effective dam operation concept, hourly inflow flood hydrograph for flood prediction is simulated by IFAS (**Figure 2**). The graph of peak inflow (Q) vs total volume (V) is plotted by using past flood events as shown below in **Figure 2**. Then by using this graph a correlation (or a function) for total volume can be found in terms of inflow.

$$V = f(Q)$$

Hourly volumes can be calculated by applying this formula if the relevant hourly inflow is known. Hourly inflow is predicted by the inflow hydrograph and hence hourly volume differences (dV) for these inflows can be simulated. Therefore, dV/dt given in below formula can be calculated. Finally, this helps to calculate the possible outflow discharge (Qout) since dV/dt is known for the predicted inflow (Qin).

$$Qout = \mathrm{Qin} + \frac{\mathrm{dV}}{\mathrm{dt}}$$

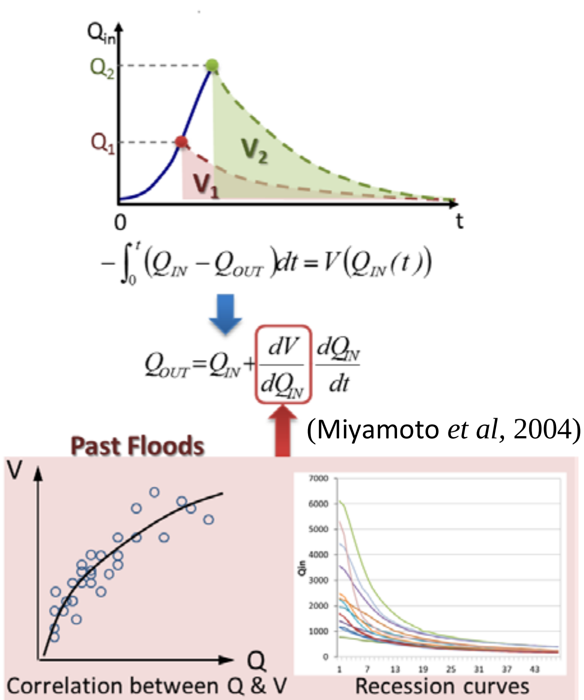

Figure 2: Prediction of total inflow volume

Above calculated possible outflow discharges then can be used to increase the flood control capacity of a reservoir as shown in **Figure 3**. The graph shows that the discharge releases based on predicted inflows have been done before inflow reached to the reservoir in a way that reservoir capacity is maintained at its full supply level at the end of the operation.

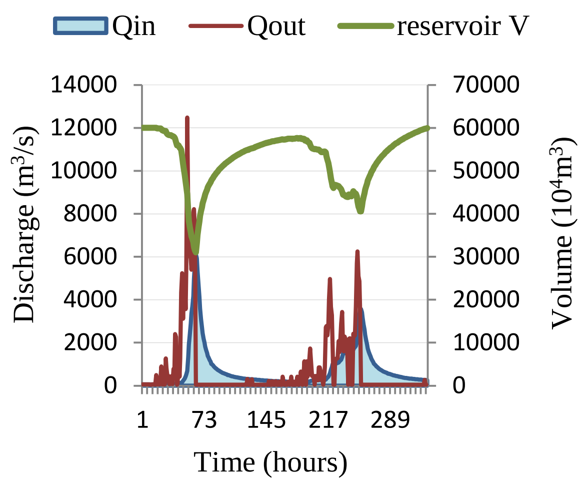

Figure 3: Possible outflow discharge

DATA

There are three rain gauge stations located within the Senanayaka Samudra watershed area and they used to measure rainfall on daily basis. However, Inginiyagala rain gauge station is out of order since year 2007. Data of the Senanayaka Samudra reservoir such as daily reservoir water level, daily discharges through sluices and area capacity curve are also available. There is no flood forecasting system and real time operation is used in flood management based on the standing operations available for the reservoir. Only few hourly spill flood discharges have been recorded during the reservoir spilling in year 2011 monsoon flood situation.

RESULTS AND DISCUSSION

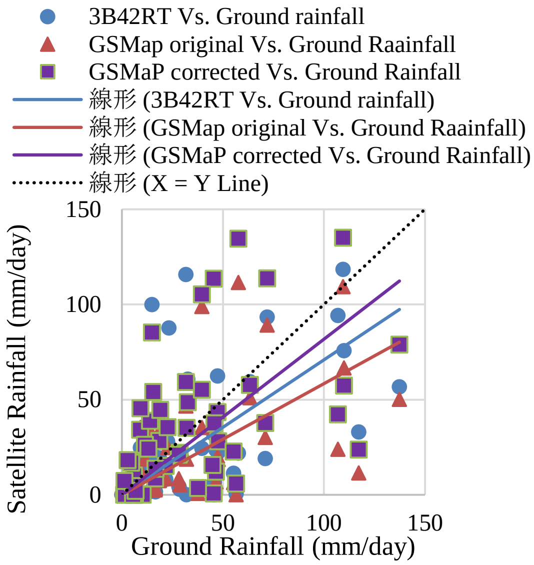

Figure 3: Relation between ground rainfall and Satellite rainfall data

Satellite and ground rainfall data for the past events affected to the Senanayaka Samudra reservoir basin were compared by plotting different sources of satellite rainfalls against ground rainfall (Figure 3). As per Figure 3, it is shown that the daily rainfall of GSMapNRT data Corrected by ICHARM method agree to daily Ground rainfall data than the 3B42RT and GSMaP original data. Therefore, GSMaP corrected rainfall data were used for the IFAS

In effective dam operation concept, reservoir inflow is forecast and the preliminary release is done before flood takes place. As per the data availability in the study area, a correlation is built between basin rainfall and the relevant inflow volume so that the reservoir inflow can be predicted with respect to the catchment rainfall. Based on the data availability, two approaches were considered for finding the correlation (**Table 1**).

Table 1: Data availability

Approach	Rainfall	Inflow	Time Interval
1	GSMaP corrected	IFAS results	Hourly
2	Ground observed	Ground observed	Daily

The correlations developed by approach 01 & 02 were compared and combined Correlation was also plotted (**Figure 4**). Linear correlations given by approach 01 and combined event (hourly and daily) are corresponding and selected for the analysis.

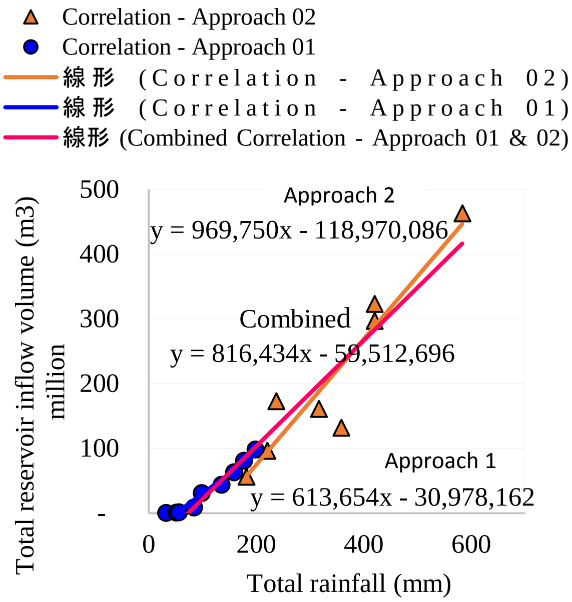

Figure 4: Different correlations

The risk of releasing preliminary gate discharges based on inflow prediction was curtailed by 50% with the introduction of 50% reduction to the original correlations (**Figure 5**). In other words, 50% less inflow volume from original correlation will be predicted by using new correlations and preliminary gate release can be cut off by half. Further, **Figure 5** shows both 50% less correlations lie below all the past inflow volumes considered in this study.

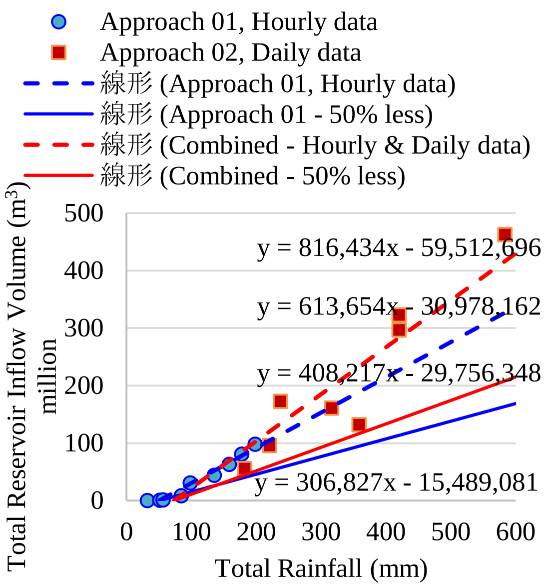

Figure 5: Introduction of 50% reduction to reservoir inflow volume prediction

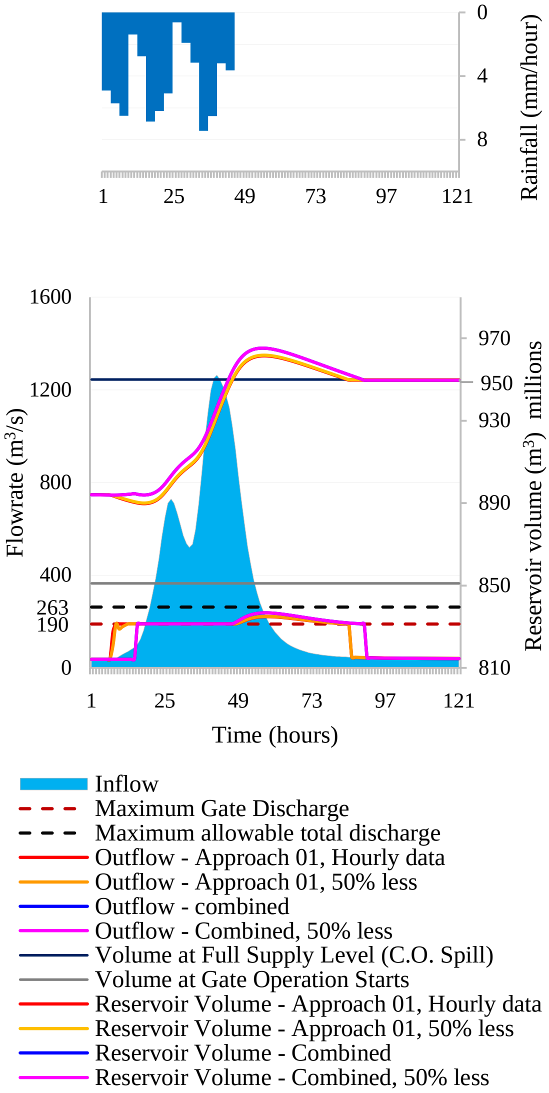

Figure 6: Dam operation with different correlations

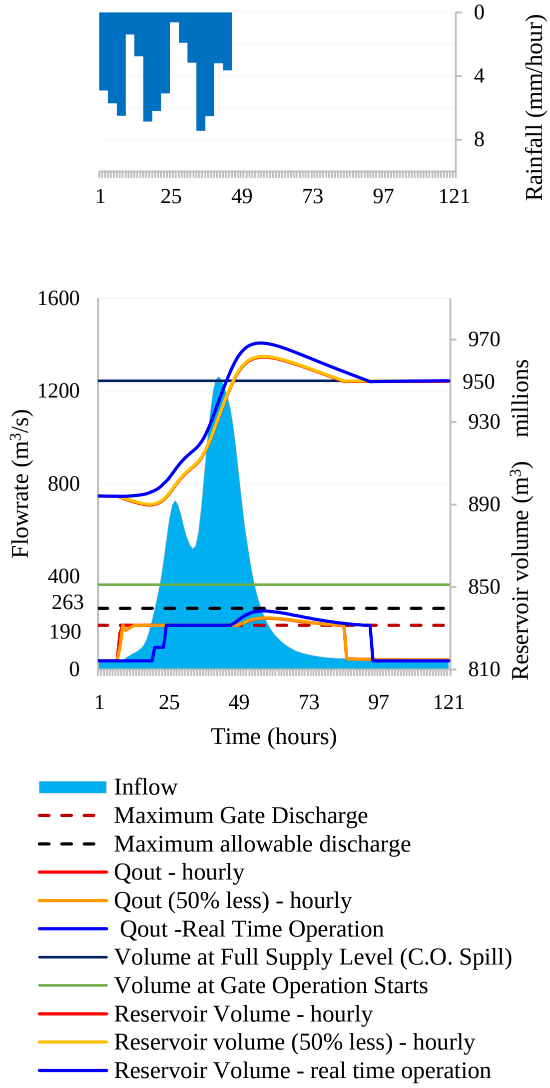

Figure 7: Comparison of inflow forecasting and real time dam operations

Dam operation with different inflow prediction correlations were illustrated in the **Figure 6**. In both hourly and combined correlations, inflow forecast by original correlation and 50 % less methods give much closer results. This is because, predicted inflow at the beginning exceeds the maximum gate outflow by leading them to be fully opened during the particular rainfall event. The gate operations for hourly correlation and combined correlation start at 8th and 16th hours respectively after rainfall commenced. The gate operation period with the inflow prediction by using combined correlation is less than the operation based on hourly correlation due to the additional uncontrolled outflow over the spill caused during the first case. In all cases preliminary discharges can be issued before inflow reached to the reservoir and maximum outflow is well within the threshold limit of 263 m^3/s. However, preliminary discharge by using combined correlation delays by 8 hours in comparison to the preliminary discharge made by hourly correlation due to the difference of initial cumulative rainfall loss considered.

The **Figure 7** shows the comparison of real time dam operation based on existing standing orders and the dam operations based on inflow predictions. Hourly and its 50% less inflow prediction correlations were selected for inflow prediction in the analysis. The real time operation starts with the prevailing reservoir inflow. Cumulative rainfall at the commencement of the real time gate operation is higher and about 134 mm. Preliminary discharge by inflow prediction methods can be started 12 hours earlier than by the real time flood operation. Peak discharge released by forecasting method has been reduced by 11.5 % from the real time operation. Spilling time (or uncontrolled flood discharge period) for real time flood operation is longer by 11 hours than the forecasting method. Peak discharge by the real time operation is nearly close to the maximum allowable reservoir outflow of 263 m^3/s.

CONCLUSION

In this study of effective dam operation based on inflow forecasting, early release based on upstream reservoir basin rainfall is assured and peak discharge is reduced in comparison to the existing real time dam operation. Further, due to the reduction in peak discharge of Senanayaka Samudra reservoir along Galoya River, more downstream flood water can occupy in the river. This ensures convenient decision making in downstream flood management. The effective dam operation concept also allows more flood operation through flood gates rather than uncontrolled spillover which is also very much helpful in downstream flood management. Flood travelling time of the selected basin in this study is less than 24 hours. The data available for this basin are daily ground rainfall for 3 gauge stations and daily measured reservoir inflow data with only one event of hourly measured reservoir inflow. Application of IFAS, validation of different rainfall products and suggestions of effective dam operation method based on hourly inflow forecasting for the Senanayaka Samudra reservoir basin with the help of above data are the major findings in this study.

RECOMMENDATION

The Senanayaka Samudra reservoir basin consists of 3 rain gauge stations which used to measure rainfall on daily basis. These gauges are poorly distributed within the basin and one gauge is currently out of order. Hourly ground rainfall data and the accuracy of the ground rainfall data are very important in inflow forecasting. Therefore, new rain gauge stations properly distributed within the basin are recommended to establish for measuring high quality hourly basis data. Reservoir inflow is one of the important calculation made in this study. Since there is no hydro-metrological station to measure river water levels or inflows at the upstream of the reservoir, total hourly reservoir inflow are calculated by using available reservoir data such as water levels, area capacity curve and discharges. The accuracy of reservoir inflow calculation by using these data depends on the reservoir water loss, accuracy of area capacity curve and the applicability of formulas for calculating gate and free overflow spill discharges. Therefore, it is recommended to establish a river inflow gauge stations at the upstream of the reservoir to have a better estimation and comparison of reservoir inflows.

Senanayaka Samudra reservoir comprises of Galoya river and 2 main canals connected with medium reservoirs. In additional, there are some isolated reservoirs located at the downstream of the Senanayaka Samudra reservoir. When monsoon rain prevails most of these reservoirs tend to spill simultaneously and large amount of spill water accumulated to the Galoya river. So far, the proper study of flood peak travelling time for these spill water has not been done. Therefore, the combination of the results obtained from this study and further study of downstream canal, river and reservoir system may maximize the flood management at downstream of Senanayaka Samudra reservoir.

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