Optimal reservoir operations under inflow scenarios in Nam Ngum River basin using Mixed-Integer Nonlinear Programming

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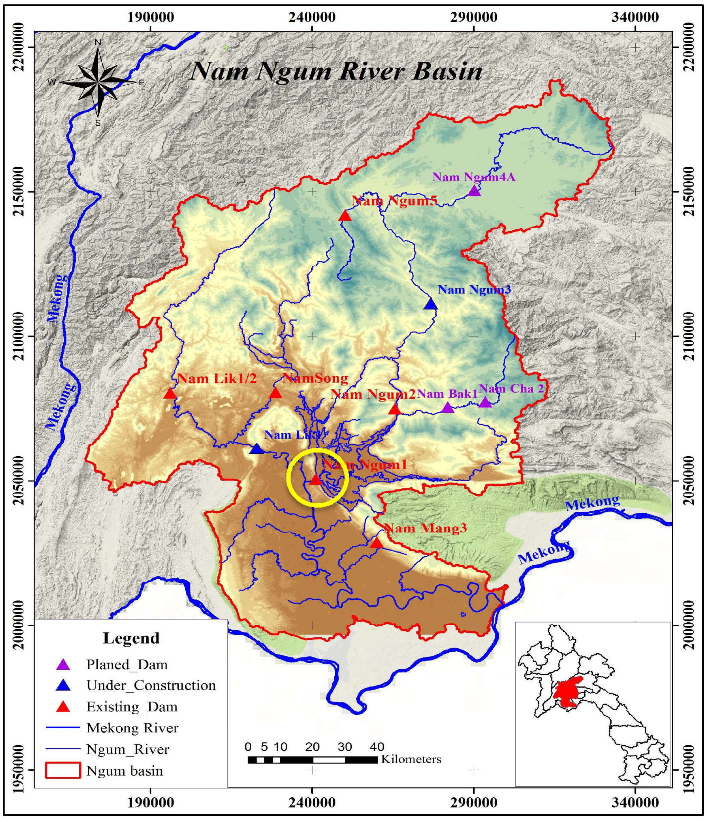
Research outline

1. Introduction
2. Research objectives
3. Methodology
4. Results and discussion
5. Conclusion and further research

Introduction

- ❑ Laos aims to be the **"Battery of Asia"** by exporting hydropower to neighboring countries (MDGs of Laos, 2011).
- ❑ Nam Ngum River is the fourth largest river in Lao PDR, the area of the river basin is 16,931 km^2
- ❑ The total 11 dams are in the Nam Ngum River basin (NNRB)
  - ❖ 6 existing dams have operated for the hydropower generation until now,
  - ❖ 2 dams are under construction
  - ❖ 3 dams are in the plan.
- ❑ Population growth rate of 14.7% from 2005 to 2015.
- ❑ Economic development (Maga projects)
- ❑ The average electric power demand in 2000 to 2016 has increased approximately 10% every year.

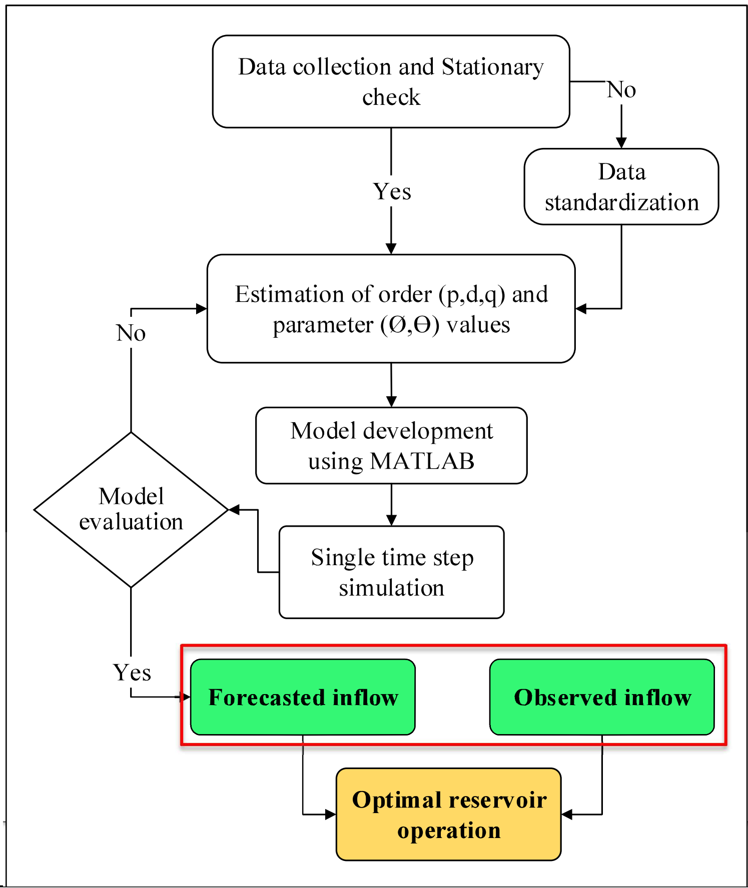


Research objectives

1) To maximize the hydropower production under different reservoir inflow scenarios (observed inflow and inflow forecasting from time series model).

2) To propose operational guideline for reservoir operation optimization of others reservoir in Nam Ngum River basin.

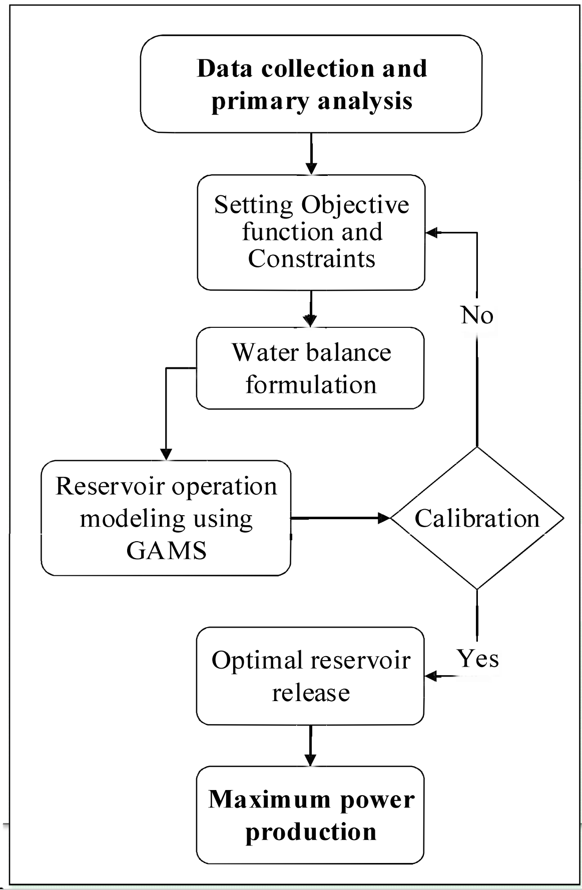
Methodology



Inflow forecasting

- ❑ Autoregressive Integrated Moving Average (ARIMA) model is selected for reservoir inflow forecasting.
- ❑ Five model candidates were tested to find the best model based on AIC value.
- ❑ Observed inflow of 14 years (2002–2015) are selected:
  - 2002 - 2011 used for calibration.
  - 2012 - 2015 used for validation.
- ❑ One time step forward method is used to forecast inflow.
- ❑ The performance of model will be evaluated by:
  - Coefficient of Determination (R^2)
  - Root Mean Square Error (RMSE)

Methodology



Optimization modeling

- ❑ Mixed Integer Nonlinear Programing (MINLP) used for this research is an optimization solver tool in GAMS software.
- ❑ The main equation in software is the water balance equation

$$S_{t+1} = S_t + In_t - E_t - R_t - Spill_t$$

- ❑ **Objective function**

Maximize hydropower production

$$Maximize: \quad P_{Total} = \sum_{t=1}^{n}(\eta \times \gamma \times R_t \times H_t \times T)$$

- ❑ **Constraints**

- Storage level $S_{\min} \le S_t \le S_{\max}$
- Turbine release $R_{\min} \le R_t \le R_{\max}$
- Gross head $H_{\min} \le H_t \le H_{\max}$
- Power generation $P_{\min} \le P_t \le P_{\max}$

- ❑ Decision variables of the problem is the amount of water released from the turbine.

Model selection result

Model selection based on AIC value

No.	Model candidate	AIC value
1	ARIMA(1,1,1)	235.881
2	ARIMA(2,1,1)	198.212
3	ARIMA(2,1,2)	228.304
4	**ARIMA(2,1,3)**	**183.810**
5	ARIMA(3,1,3)	196.261

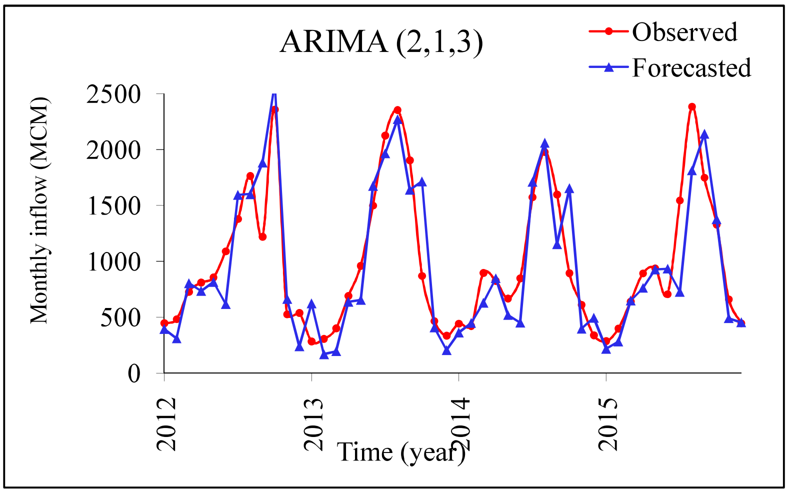
ARIMA (2,1,3) has minimum of AIC value, so this model is selected for monthly reservoir inflow forecasting for this study.

Parameters estimation result

Selected model	Parameters				
	$\varnothing_1$	$\varnothing_2$	θ_1	θ_2	θ_3
ARIMA (2,1,3)	1.4322	-0.6505	-0.1053	-0.154	-0.3223

Inflow forecasting result

Comparison between observed and forecasted inflows



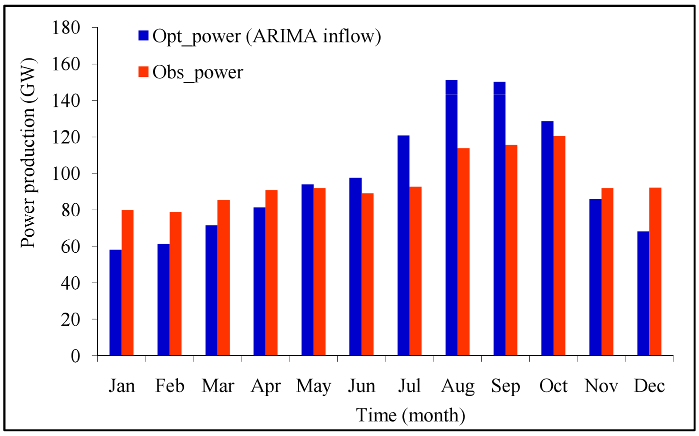
Model performance

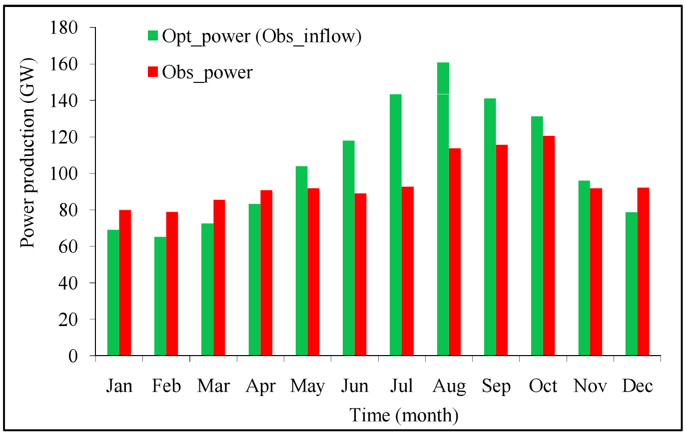
Statistical index	Value
R^2	0.78
RMSE (MCM)	115

In the figure, it is clear that the ARIMA (2,1,3) model can capture the overall pattern of low flow and high flow characteristics when compared to observed inflow. However, in 2012 and 2015 are underestimates forecasted and detect peak too late.

Optimal reservoir operation results

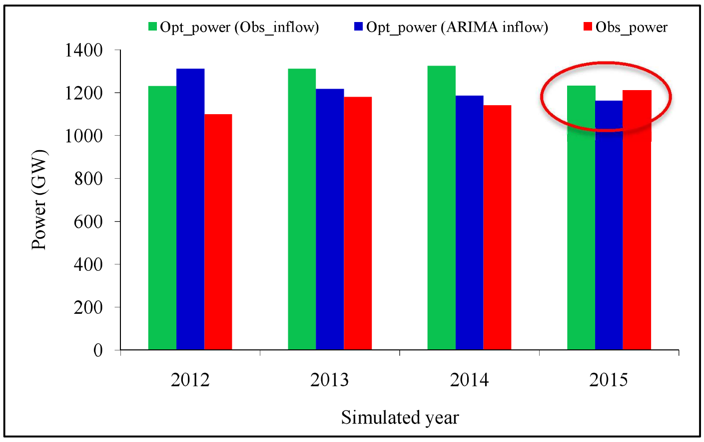
1. Comparison of monthly hydropower production





In both scenarios, the maximum power production occurred during wet season grater than the observed, but in dry seasons is less than the observed. This difference demonstrated that the uncertainty from the inflow forecasting model affected to the reservoir operations.

2. Annual hydropower production



Year	Observed power (GW)	Optimized power (GW)	
		ARIMA_inflow	Obs_inflow
2012	1,040,707	1,312,074	1,230,977
2013	1,180,196	1,218,496	1,312,170
2014	1,141,816	1,185,843	1,324,773
2015	1,209,683	1,159,911	1,230,811
Average increase (%)		**2.22**	**12.25**

The results shown that annual hydropower production were increased of 12.25% and 2.22% from optimization under observed inflow and ARIMA inflow, respectively.

However, Figure demonstrated that in 2015, the hydropower production was slightly less than observed power. This may be due to the inflow from ARIMA is lower than observed inflow in some months, because ARIMA forecasted only one month forward time step accept observed inflow is already known all period of time series data.

Conclusion

- ARIMA (2,1,3) was accepted for forecasting monthly reservoir inflow because it outperformed other model in capturing low flow and high flow characteristics.
- The optimization model can improve the hydropower production of 12.25% and 2.22% from optimization under observed inflow and ARIMA inflow, respectively.
- These results provide a useful means to decide for the optimal amount of water release for in short term and long term of water resources planning.
- This method is possible to be operational guideline for others reservoirs in Nam Ngum basin

Further research

- Further research for simulating inflow with uncertainty e.g. from climate change should be investigated further to better capture future conditions.
- For the optimal reservoir operation model, it is needed to improve objective functions and constraints to more explicitly address the flood at the downstream.
- The results obtained from this study should be extended to be applied for multiple multipurpose reservoir operations.

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Thank you

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