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Abstract	This study deals with the development of a method to estimate the stock projection for Linggiu Reservoir (LR) under climate change scenarios. This study found that the projected rainfall data for the reservoir was comparable and very close to the observed rainfall data. Based on the LR stock projection using average and minimum rainfall projected under different climate change scenarios, it was observed that the stock was expected to be below 60% throughout the four years (2018–2021). In addition, the stock for LR (2022–2027) was projected to achieve the consistent maximum stock, which is 760 MCM. In the future, it is useful to prepare a sustainable water supply action plan for LR specifically to address the impact of climate change such as drought and El Niño episodes.
Keywords	Reservoir - Resilient storage - Climate change



Towards Resilient Storage for Water Supply Dam Under Climate Change Scenarios: A Case Study of Linggiu Reservoir

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Abstract. This study deals with the development of a method to estimate the stock projection for Linggiu Reservoir (LR) under climate change scenarios. This study found that the projected rainfall data for the reservoir was comparable and very close to the observed rainfall data. Based on the LR stock projection using average and minimum rainfall projected under different climate change scenarios, it was observed that the stock was expected to be below 60% throughout the four years (2018–2021). In addition, the stock for LR (2022–2027) was projected to achieve the consistent maximum stock, which is 760 MCM. In the future, it is useful to prepare a sustainable water supply action plan for LR specifically to address the impact of climate change such as drought and El Niño episodes.

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Keywords: Reservoir · Resilient storage · Climate change

1 Introduction

In the current context, Malaysia has been well known to be vulnerable for climate change issues. It was predicted that climate change can affect water resources [1]. If there is no concrete action on water resources management, the potential impacts on these resources were likely to increase in magnitude, diversity, and severity. It is also evidenced that climate change impacts on water resources can be both, direct and indirect effects on several aspects including agriculture, health, ecosystems, and biodiversity as well as energy generation [2, 3]. It is exhibited in literature that several areas in the world would experience water supply problems in the future [4, 5]. Knowledge on the management of reservoir in response to future climate changes is useful water management practices [6, 7]. Hence, it is needed to enhance the understanding of climate change impact on reservoirs [8, 9].

Malaysia can be categorized as a country having high annual rainfall and adequate water resources [10]. However, there were evidences that several states in the country

experienced water crisis possibly due to uncertainty of climate. Johor Basin is relatively a low-lying area, especially in the middle and downstream parts of the river, some areas experienced floods during rainy season and saline intrusion during the dry season. In the past, this situation has resulted in the development of a water resource system which requires a large capacity of 760 million cubic meters for the Linggiu Reservoir.

In this paper, we propose a method for the stock projection for Linggiu Reservoir (LR). This work is valuable for decision makers for proper reservoir management particularly for LR in assessing the future reservoir resilience under climate change scenarios.

2 Methodology

2.1 Site Location

Constructed by The Public Utilities Board, the (LR) is located upstream of the Johor River. It provided water supply for Johor, Malaysia and Singapore. It has a catchment area of about 208 km². Full supply level, crest width, reservoir height, and minimum operating level for LR are 51 m, 9.1 m, 39 m, and 26 m, respectively.

2.2 Stock Projection Estimation

LR Stock projection model is related to the addition and reduction of stock/storage in the reservoir based on LR rainfall and release on monthly basis. The LR stock projection for 12 months was presented in this paper with additional LR stock projection from 2018 to 2027 based on projected rainfall data provided by National Hydraulic Research Institute of Malaysia (NAHRIM).

Briefly, the LR Stock Projection Model algorithm was constructed by analyzing the input and output parameters related to the addition and reduction of storage/stock in the reservoir based on LR rainfall and release on monthly basis. The input parameters used for the stock projection were weighted historical rainfall data in LR catchment area and LR release from 2011 to 2017 (see Table 1) provided by public utilities board (PUB). Extreme weather conditions impact from climate change have become more frequent in many countries including Malaysia. The effect of climate change needs to be taken into account in the LR stock projection model. For this study, it has been decided that a series of model rainfall data from year 2019 to 2027 based on fourteen climate change scenarios (CCSM3A1B, CCSM3A2, CCSM3B1, ECHM5A1B1, ECHM5A1B2, ECHM5A1B3, ECHM5A2_1, ECHM5A2_2, ECHM5A2_3, ECHM5B1_1, ECHM5B1_2, ECHM5B1_3, MRIA1B, and MRIB1) provided by NAHRIM.

Table 1. Statistical indicator for data used in this work.

Data	Statistical indicator	Value
Monthly rainfall (mm)	Min	36.1
	Mean	191.3
	Max	540.0
	SD	94.3
Storage (ML)	Min	161026.0
	Mean	539922.9
	Max	779868.0
	SD	218367.7

3 Results and Discussions

3.1 Stage Storage Curve

Figure 1 shows the stage storage curve for LR. It can be observed that at the minimum stage of 25 m, the storage for LR was about $2 \times 10^6 \text{ m}^3$. In addition, storage for LR at the stages of 36 and 47 m are 149 and $604 \times 10^6 \text{ m}^3$, respectively.

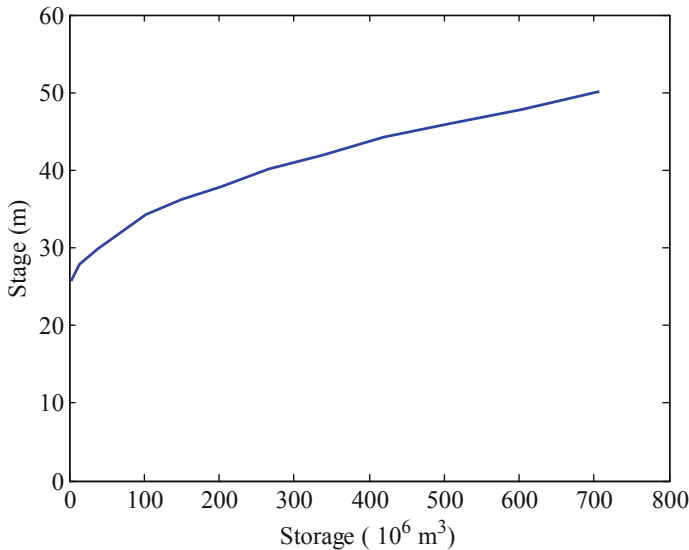


Fig. 1. Stage storage curve for LR

3.2 Reservoir Yield

The following estimation method was based on 100-day of zero flow river yield. It was found that LR full stock is 760 MCM. Assuming the critical storage condition of 30% and evaporation balances with dry weather LR catchment recharge, the balance is 760

MCM multiplies by 70% equals to 532 MCM for 2 years low flow operational storage. Therefore, approximately 266 MCM (35%) is for one-year low flow operational storage. Dividing one-year storage by 100 days cumulative of low flow, the yield for LR storage is 2,660 MLD. With abstraction of around 2,000 MLD, the balance of the LR storage yield is 660 MLD.

3.3 Historical Stock for LR

This study found the reduction trend of LR stock due to El Nino event which occurs during year 1996~1998, year 2009~2010 and the worst is in year 2014~2016. During the worst El Nino events in year 2014~2016, it requires more than a year to recover back to its full capacity.

3.4 Stock Projection

This section presented the projection of LR stock starting from year 2018 to 2027. The projection was based on projected rainfall data from year 2019 to 2027 provided by NAHRIM under the minimum rainfall projection model which is CCSM3B1. This model was selected because it performed minimum cumulative rainfall for year 2019 to 2013 and 2019 to 2024 period compared to 13 climate change (CC) models of rainfall projection. Figures 2 and 3 illustrate the projected pattern of LR stock for 2018 to 2027.

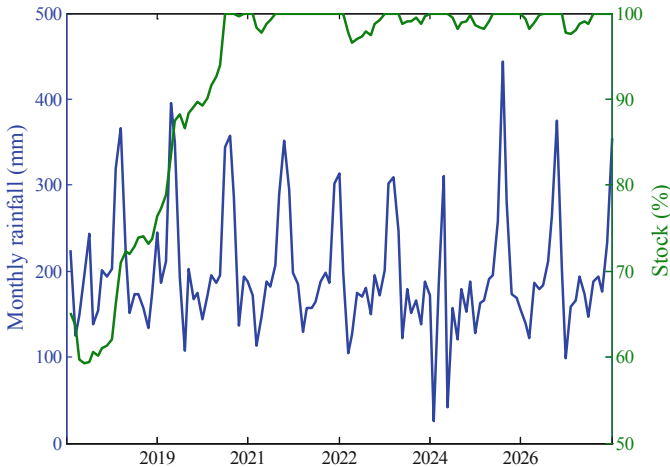


Fig. 2. LR stock projection (2018–2027) based on the projected average rainfall from fourteen CC scenarios

It is forecasted that the stock level at the end of 2018 is estimated to be 71% based on average flow data. As a comparison for minimum rainfall as shown in Fig. 3, the stock level is projected around 54% at the end of 2018. The stock level was projected around 87% at the end of 2019 under the average rainfall scenario whereas under the

minimum rainfall, the stock level was projected around 56% at the end of the year. In 2020, for average scenario it is expected that the reservoir will be filled up from 88 to 100%. However, for minimum rainfall throughout the period 2020, LR stock was expected to be only in the range of 40 to 58%.

As shown in Fig. 2, for average scenario it is expected that the reservoir would be filled up during most part of the year 2022. But for minimum rainfall scenario, an addition of LR stock to 90% at the end of the year. In addition, the average scenario continues to fill up the reservoir for the whole year 2024. However, LR stock decrease to 78% at the end of the year for minimum rainfall scenario.

In Fig. 2, for average scenario it is expected that the reservoir will be filled up during most part of the year 2026. But for minimum rainfall scenario, the highest projection can only achieve up to 65%. Similar situation in 2027 was also observed for the LR stock projection under average scenario. This study found that the LR stock projection under average scenario can achieve up to 100% during most part of the year 2027. However, LR stock projection under the minimum rainfall scenario can be only in the range of 50 to 76% with the highest predicted occurred on December.



Fig. 3. LR stock projection (2018–2027) based on the projected rainfall from CCSM3B1 scenario

Figures 4 and 5 show the harvest and storage for LR projections (2018–2027) based on the projected average and minimum rainfall scenarios. The volume of water estimated to be harvested based on the average rainfall scenario in 2018 can reach 4.1×10^4 ML. As a comparison, the projected water that can be harvested can achieve only 1.4×10^4 ML at the end of the year. For 2023, the volume of water to be harvested based on the average rainfall scenario was in the range of 1 to 4.2×10^4 ML. In addition, the projected water that can be harvested for the same year are between 3 to 29×10^4 ML.

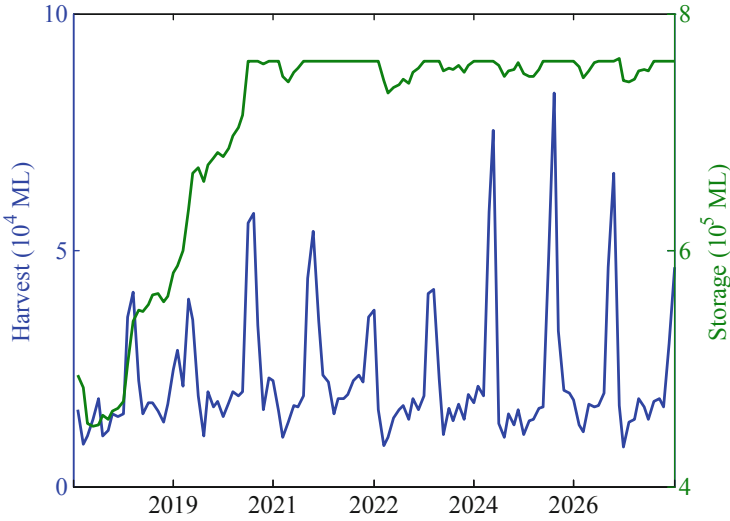


Fig. 4. Harvest and storage for LR projections (2018–2027) based on the projected average rainfall from fourteen CC scenarios

In 2024, the volume of water estimated to be harvested based on the average rainfall scenario was 75×10^4 ML at the end of the year. Alternatively, the projected water that can be harvested can achieve only 36×10^4 ML at the end of the year. The

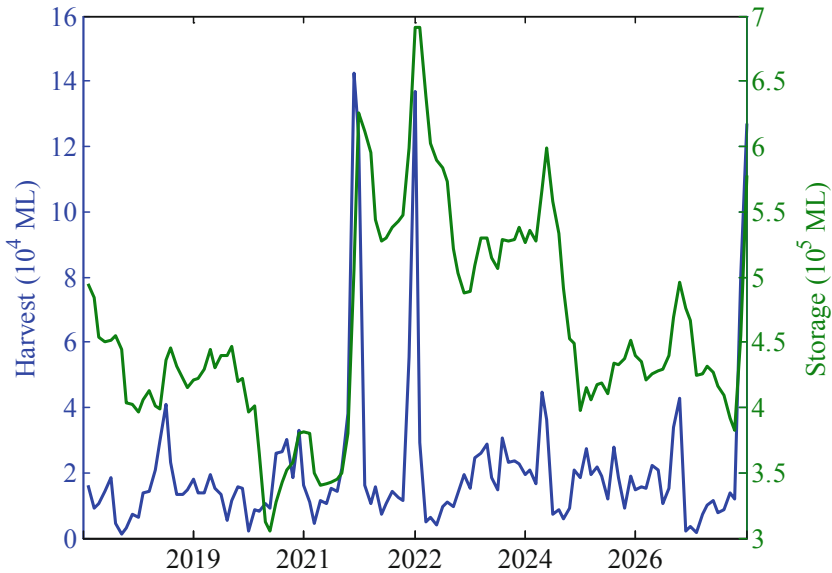


Fig. 5. Harvest and storage for LR projections (2018–2027) based on the projected average rainfall from CCSM3B1 scenario

volume of water to be harvested based on the average rainfall scenario was in the range of 10 to 83×10^4 ML as exhibited in 2025. In addition, the projected water that can be harvested for the same year are between 5 to 28×10^4 ML.

4 Conclusion

The aim of this study was to propose a method for the stock projection for Linggiu Reservoir (LR) under climate change scenarios. This study exhibited that the projected rainfall data was very consistent with the observed data and was reasonable for the LR long-term projection. It was also found that the projected stock was expected to be below 60% throughout the four years (2018–2021). In addition, the projected stock for LR (2022–2027) was predicted to achieve the maximum stock. The scope of this study was limited on the estimation of stock only by using future rainfall projection. Findings from this study are useful for decision makers for proper reservoir management particularly for LR.

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