Future Climate Effects on Lake Volume of Sembrong Dam using MRI-AGCM3.2s

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ABSTRACT: Sembrong Lake acts as a dam and provide water supply to the people around Batu Pahat and Kluang. In the future, the population may increase as the area around Sembrong Dam is still developing. Sembrong Dam has been observed to be having water quality problems such as an increasing of algae bloom. Besides water quality, water quantity is another factor contributing to the problems. Future climate implications on the hydrological processes may affect the water quantity of the dam. Study of changes of lake volume in the future is also limited. In order to assess the climate effect on lake volume, water balance equation is used. Water balance model was developed to analyse the changes in water storage of the dam. The data used for the water balance analysis were rainfall, evaporation, runoff, water intake and environmental flow. Runoff was calculated based on a conceptual model called WATBAL. Rainfall, evaporation and water intake data were obtained from Department of Irrigation and Drainage (DID). Analysis were conducted for present and future conditions for comparison. Present and future data was represented by the year 2005 to 2013 and 2079 to 2099 respectively. Future data were obtained from a Japanese Atmospheric General Circulation Model, MRI-AGCM3.2s. The data were calibrated and validated using bias-correction method and error analysis. Comparison between observed and calculated lake volume and changes in lake volume shows an RMSE of 0.10 and 0.33 and R^2 of 0.88 and 0.21, respectively. Future changes in the lake volume have lower values compared to present due to the decreasing value of precipitation and the increased evaporation in the future. Climate change will not have significant effect in the lake colume changes of Sembrong Dam.

Keywords: Sembrong Dam, Water balance model, Storage Estimation; Japanese MRI-AGCM.

1.0 INTRODUCTION

Sembrong Dam is located about 10 km from Air Hitam town in the state of Johor. It was completed in 1984 initially as a flood-control dam. Later, it was tapped with Syarikat Air Johor (SAJ) for water supply since then. The dam is surrounded by oil palm plantation. The dam's catchment area is about 130 km^2 with capacity of 18 million m^3 and dam height of 11 m as it drained from Sg. Sembrong. Along the Sembrong River, the land activities are inclusive of industrial areas, residential areas and agricultural activities such as palm oil mill and paddy fields. After around 10 years, SAJ Holdings Sdn. Bhd. were licensed to extract 2.6 million m^3 per month. However, the maximum water intake recorded in 2015 is 2.1 million m^3 [1]. Hydrologic changes related to climate change may affect the water-supply demand balance[2].

1.1 Problem Statement

Climate change may impact the water storage due to the changes in precipitation, rising surface temperature and also the increasing of the evaporation. In order to ensure the water supplies continuously be available in the future, it is important to analyze the quantity of future water storage of the dam. However, using water balance model, only the changes of the lake volume may be assesed due to the limitation in estimating the initial dam volume in the future.

1.2 Objectives

The aim of this study is to assess the changes in water storage of Sembrong Dam in the future.
The specific objectives that are going to be achieved by this study are:

1. To develop and validate water balance model for Sembrong Dam
2. To analyse the climate change effect towards the changes of lake volumes

1.3 Scope of Study

This study is focus on Sembrong Dam located at Johor. Investigating and determining the changes of lake volume of the dam. The global scale of MRI-AGCM used in this study is 20 km also known as MRI-AGCM3.2s. MRI-AGCM3.2s only was used to analyze the future water balance model to identify the changes of lake volume. WATBAL model (rainfall-runoff conceptual model) was used to calculate the value of runoff. Future climate data of the scenario RCP8.5 from the MRI-AGCM where considered as the worst case scenario regarding the situation today.

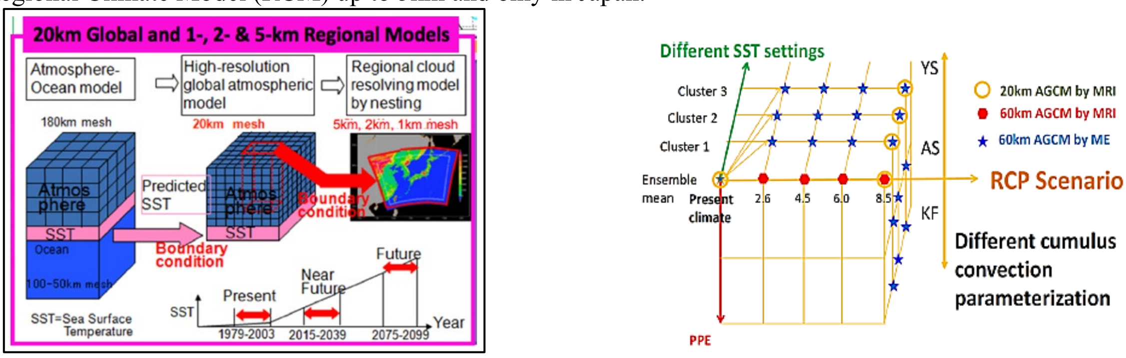
2.0 LITERATURE REVIEW

2.1 Sembrong Dam

Sembrong Dam is located around Batu Pahat and Kluang,Johor. This dam consists of lake area of 8.2km^2. The average water depth of the dam is 9m. The size of the cathcment approximately around 130 km^2. The previous study of Sembrong Dam that focus on water quality have been done by National Hydraulic Research Institute of Malaysia (NAHRIM). The condition of the lake also have been stated in The Star's Newspaper on 17th March 2015 with the headline "Sembrong Dam 'Slowly Dying'" where the condition of the dam may affect the future water storage of the dam. Besides water quality,water quantity of the dam might as well be affected in the future. Therefore, water balance equation is used to estimate the storage of the dam by analysing the changes of the lake volume.

2.2 MRI-AGCM3.2s

Global Climate Model (GCM) is the primary source of information for constructing climate scenarios and it also provides the basis for climate change impact assessments at all scales. Basically, the models will give the output based on present, near future and future data. MRI-AGCM3.2s take the time series of present from 1979-2003 due to the release of carbon dioxide is high during that time from the industrial expansion. Future projections range from 2079-2099 to represent the end of the century. The present and future climates data were simulated by using the observed sea surface temperature (SST). The SST projected by Atmosphere–Ocean coupled models is used as the lower boundary condition for the MRI-AGCM3.2s. The Atmosphere-Ocean coupled models which are known as Couple Global Climate Models (CGCM) are under Climate Model Intercomparison Project Phase 5 (CMIP5) where this project is conducted by Intergovernmental Panel on Climate Change (IPCC). The Meteorological Research Institute (MRI) of Japan has developed one GCM model called the MRI-AGCM with a global scale of 60 km (MRI-AGCM3.2H) and 20 km (MRI-AGCM3.2S) resolution. A downscale of the 20 km MRI-AGCM is developed under the SOUSEI Program which downscale the GCM to Regional Climate Model (RCM) up to 5km and only in Japan.



(a) (b)

Figure 1: (a) Regional Models (b) Single Model Ensemble

Figure 1 shows the Single Model Ensemble from the AGCM. The scenario used for the future climate data is RCP8.5. From the scenario, the condition of the world today is in the worst case scenario (4 degree changes around the world). [6]

2.3 Water Balance Model

The study of the water balance structure of lakes forms a basis for the hydrological substantiation of projects for the rational use, control and redistribution of water resources in time and space. Knowledge of the water balance assists the prediction of the consequences of artificial changes in the regime of streams, lakes, and ground-water basins [5]

3.0 METHODOLOGY

This research consisted of two key activities; development of Water Balance Models and prediction of future water storage changes of the dam. Table 1 explains the sources of data used in the Water Balance Model. The description of the landuse data used in the study is shown in Table 2.

Table 1: Data and Lake Description

Type of data	Present (1983-2013)	Future (2079-2099)
Precipitation	JPS	MRI-AGCM
Evaporation	JPS	MRI-AGCM
Landuse	Palm oil , kc = 1 Rubber Tree, kc = 1 Grass, kc = 0.75	Palm oil , kc = 1 Rubber Tree, kc = 1 Grass, kc = 0.75
Lake area	8.2 km^2	8.2 km^2
Catchment Area	130 km^2	130 km^2

Table 2: Landuse description

Landuse Types	Present (1983-2013)	Future (2079-2099)
Palm oil	96.4% of total landuse area	100% of total landuse area
Rubbber Tree	3.4% of total landuse area	0% of total landuse area
Grass	0.2% of total landuse area	0% of total landuse area

3.1 Development of Water Balance Models

Water balance model

The water balance model estimates the changes in lake volume. Equation (1) is used to develop the model. The changes in storage is calculated using components of, Rainfall, Evaporation, Water Intake from SAJ, as well as the Environmental flow. Comparison between calculated changes in lake volume against observed data was conducted. The relationship between lake volume and lake levels is obtained from Equation (2). Relationship between lake level in meter against lake volume in meter cube uses the Polynomial Regression as shown in the Sembrong Dam Stage-storage curve (Figure 4).

$$Changes\ in\ Lake\ Volume = Precipitation + Excess - Evaporation - Water\ Intake - Environmental\ Flow$$

(Equation 1)

$$MCM = 0.5943WL^2 - 2.26253WL - 2.6591$$

(Equation 2)

Where,

MCM = Lake volume ,(million cubic metre)

WL = Water lake level, (m)

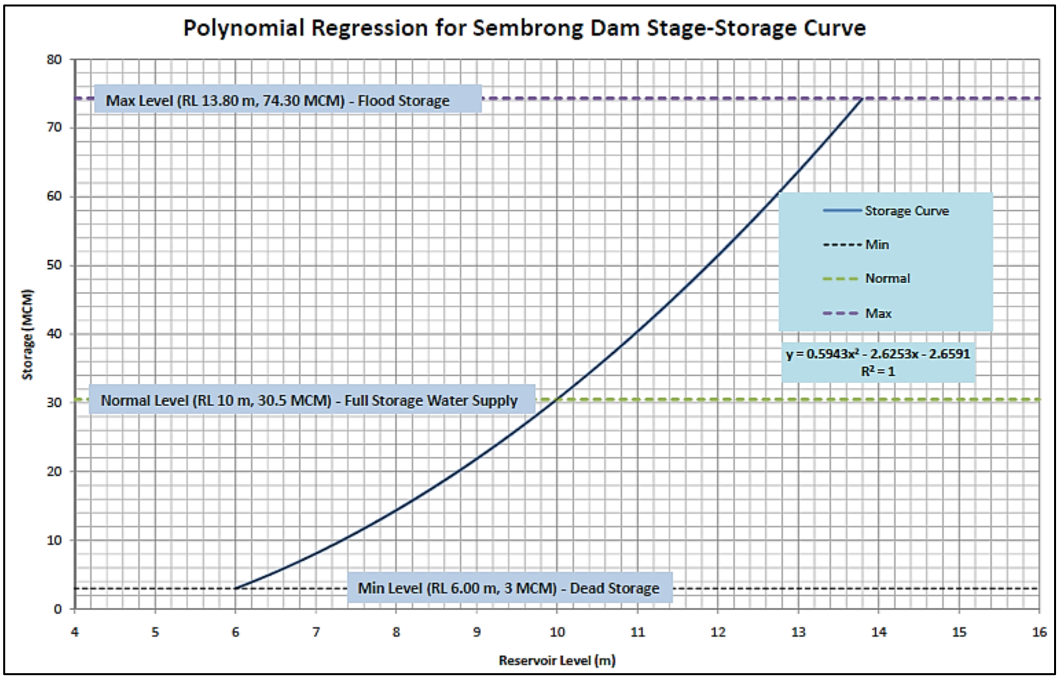


Figure 2: Polynomial Regression for Sembrong Dam Stage-Storage Curve

Data of rainfall from unit mm need to convert to m before multiplying with area of lake which is 8.2 km^2. The Evaporation components also need to change the unit and multiply with 0.9 which is the pan coefficient of open water before multiplying with area of lake. This is because all of the components in the water balance model should be in the unit of volume.

3.1.1 Present Climate Data

Precipitation

Precipitation is a major contribution to the runoff so the value of precipitation is important to be included inside the Water Balance Model. Only one station is used in this study.the details and location of the station is shown in Table 3 and Figure 3.

Table 3: Details of Precipitation data

No.	River Name	Name of Station	Station Number
1	Sg. Simpng Kiri	Empangan Sg. Sembrong di Air Hitam	1931003

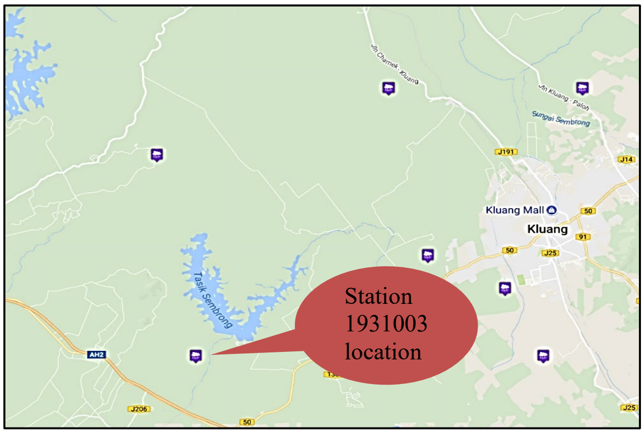


Figure 3: location of Precipitation station

Evaporation and Evapotranspiration

To estimates the rate of evaporation from a lake surface, the recorded pan evaporation (Epan) is multiplied by a pan coefficient of 0.9. The estimation of the evapotransipration of the Sembrong catchment is based on the landuse. The landuse area of Sembrong Dam's catchment is 98.2km^2. The catchment consists of 3 types of landuse which are palm oil plantation, rubber tress plantation as well as grass around the catchment. In order to calculate the value of evapotranspiration, the value of the coefficients of crop, kc(all) need to be obtained. This study combining the calculation of the 3 types of plantation consists in the cathcment. The formula to calculate kc(all) as stated in Equation (3).

$$kc_{all} = \frac{[\,A_1kc_1 + A_2kc_2 + A_3kc_3\,]}{A_1 + A_2 + A_3}$$

(Equation 3)

Where, A_1 , A_2 , A_3 = Area of the 3 different landuse,kc_1, kc_2, kc_3 = coefficient of the 3 plantation. For palm oil and rubber trees, the value of kc is 1, while the grass kc value is 0.75. The value of kc is considering the crop in the mid season condition which is the average before and after cutting known as kc_{mid}. Then, the value of evapotranspiration is calculated using Equation (4).[10]

$$ET_o = kc_{all} \times Epan$$

(Equation 4)

Figure 4: Evaporation station details and location

Water Intake and Environmental Flow

The water intake by SAJ with the value of 2.1 million m^3 is obtained from DID where the maximum number recorded on March, 2015. As for the environmental flow, it is been recorded that the value of 1.2m^3/s is continuously release from the dam.[1]

Inflow or excess using WATBAL model

The calculation of the excess is defined as the amount of water in excess of the maximum soil water storage. Due to the unknown value of the water seepage into the soil due to lack information on the soil profile, the WATBAL model is used by placing the maximum value of soil water storage as 300 mm. The excess value is known as runoff from the catchment and inflow to the lake. WATBAL model is a rainfall-runoff conceptul model which uses the water balance algorithm that can be written as:

$$ST_{i+1} = ST_i + P_i - AET_i$$

(Equation 5)

As for the excess,

$$EXCESS_i = ST_{i+1} - ST_{max}$$

(Equation 6)

Where, $EXCESS_i \geq 0$ and $0 \leq ST_{i+1} \geq ST_{max}$.

Where, ST_{i+1} is the soil water storage with the daily time step, P_i is the daily precipitation, AET_i is the actual evapotranspiration, ST_{max} is the maximum estimation of soil water storage, and $EXCESS_i$ is the excess amount of the soil water storage. All this components are in mm unit. The model calculates the water required during the time step and the excess water at the end of each time step. The excess cumulated is defined as the amount of water in excess of the maximum soil water storage. The model may be overestimate the actual runoff into lake due to the unknown amount of the deep drainage area of the Sembrong Catchment.The WATBAL model requires weekly values of precipitation and potential evaporation (PET) as input data.[7]. However, for the study, daily data was used.

3.2 Result on validation of future data

The future data of precipitation and evaporation was calibrated and validated using a bias-correction method. Table 4 shows the error analysis of the precipitation and evaporation data that have been validated and corrected.The callibration of the data uses data in year 1983-1992 while the validation of the data uses data in year 1993-2003. [11]

Table 4: Validation of Bias Corrected precipitation, evaporation and temperature using RMSE and R^2 at Sembrong Dam, Kluang.

Method	RMSE		R^2	
	Precipitation (m)	Evaporation (m)	Precipitation (m)	Evaporation (m)
1	0.40	0.06	0.87	1.00
2	0.61	0.09	0.73	0.95
3	0.39	0.07	0.87	1.00
4	0.52	0.08	0.80	0.98

3.3 Optimization method

Results of calculated and observed lake volume is plotted against the time. Comparison of the lines shows whether the calculated volume fits the observed. In order to improve the calculated values Optimization was used. suitable coefficients for each components in the Water Balance equation were identified so that both line achieved the best correlation and least root mean square error (RMSE). A good correlation and RMSE is when the value of correlation is near to 1 while the RMSE is near to zero. Water Intake and Environmental Flow components' coefficients were set to 1 while try and error of the coefficients for the other 3 components were conducted for the optimization. The equation for Optimisation method is as follows:

$$Storage\ difference = aP + bR - cE - dWI - eEF \quad \text{(Equation 7)}$$

Where, a = coefficient for Precipitation ($0 < a < 1$), b = coefficient for Runoff ($0 < b < 1$), c = coefficient for Evaporation ($0 < c < 1$), d = coefficient for Water Intake ($d = 1$), e = coefficient for Environmental Flow ($e = 1$).

4.0 RESULT AND DISCUSSION

4.1 Calibration data

4.1.1 Present Water Balance Models

The water balance model is use to estimate the changes in lake volume. Figure 5 shows the lake volume of observed and calculated against the time. The results of the calculated lake volume have been optimized using the optimizsation method. Figure 6 shows the correlation between the calculated lake volume against the observed. The correlation between calculated and observed lake volume is 0.88. This positive correlation signifies that boths variables are correlated. The nearest value to 1 means the stronger the linear relationship. RMSE between observe and calculated lake volume is 0.10. While RMSE of changes in lake volume is 0.33. The components have been optimised the coefficient value for precipitation, excess and evaporation are a=1, b=0.3 and c=0.4 respectively.

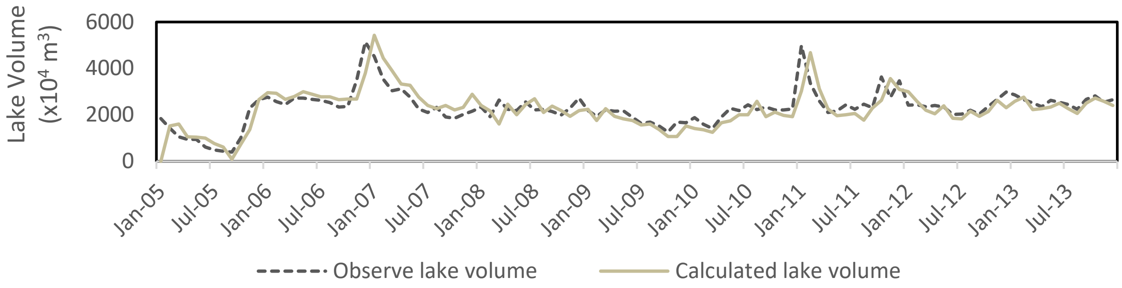


Figure 5: Lake volume of observe and calculated time series

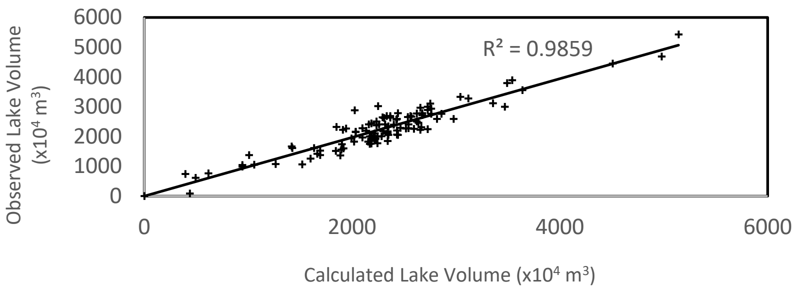
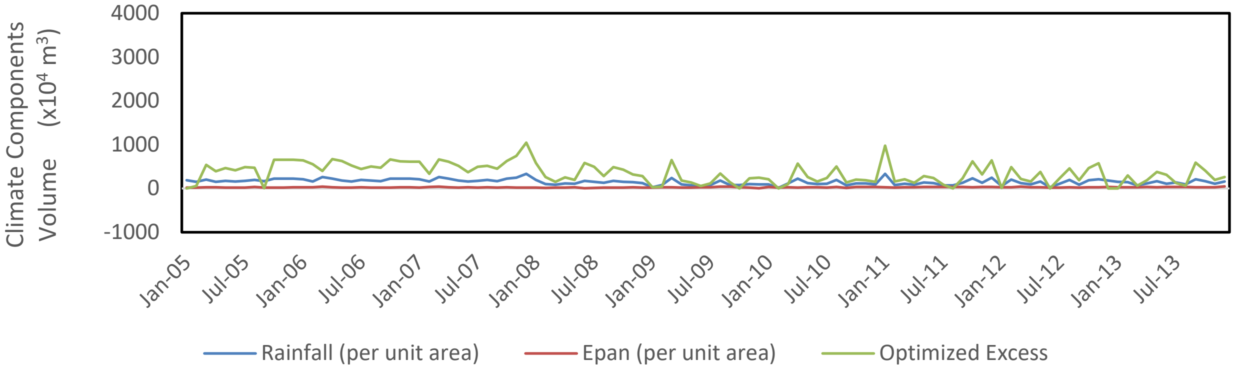


Figure 6: Correlation of Observed against Calculated Lake Volume

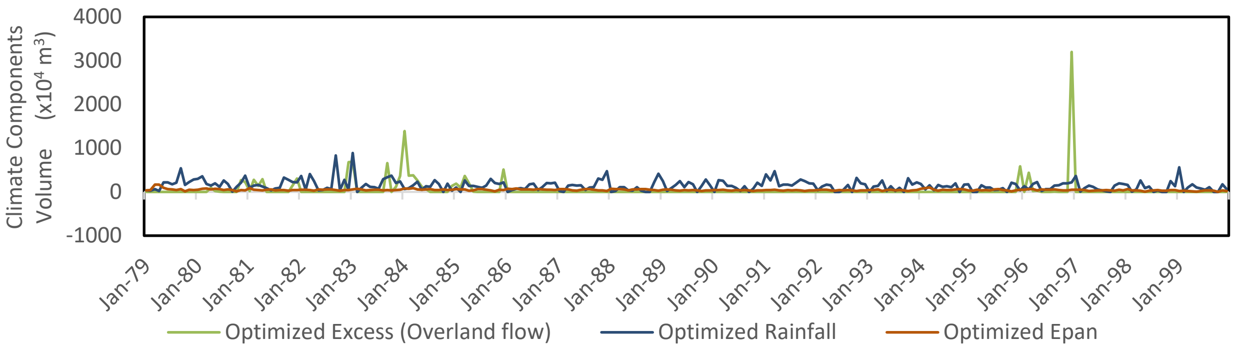
4.1.2 Water Balance Analysis based on Climate Data

Analysis without Environmental Flow and Water Intake

The analysis considers the water balance without including the value of environmental flow and water intake inside the models. This analysis is being carried out to observe the pattern of the water balance model with only considering the climate components, which are precipitation, excess from the catchment into the lake and evaporation. The results of the equation has been indicated in Figure 7 (a) present with year of 2005-2013 and (b) future with the year 2079-2099. From Figure 7, value of present rainfall is lower than the future while the future rainfall value shows flactuated pattern. For the evaporation value, the present and future were almost in a similar trend. For the excess value, present and future shows a significant difference because in the future there is a high value of excess around the year 2097 before it decrease to near zero.



(a)

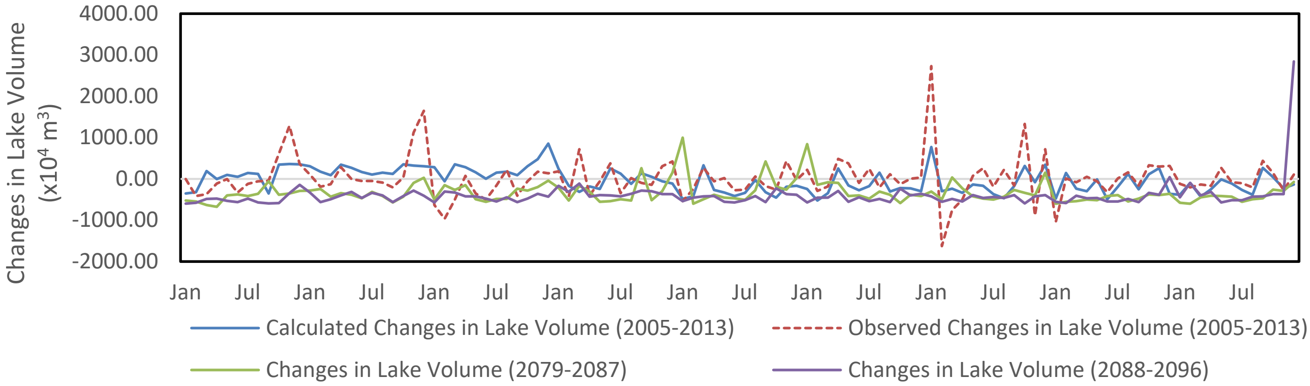


(b)

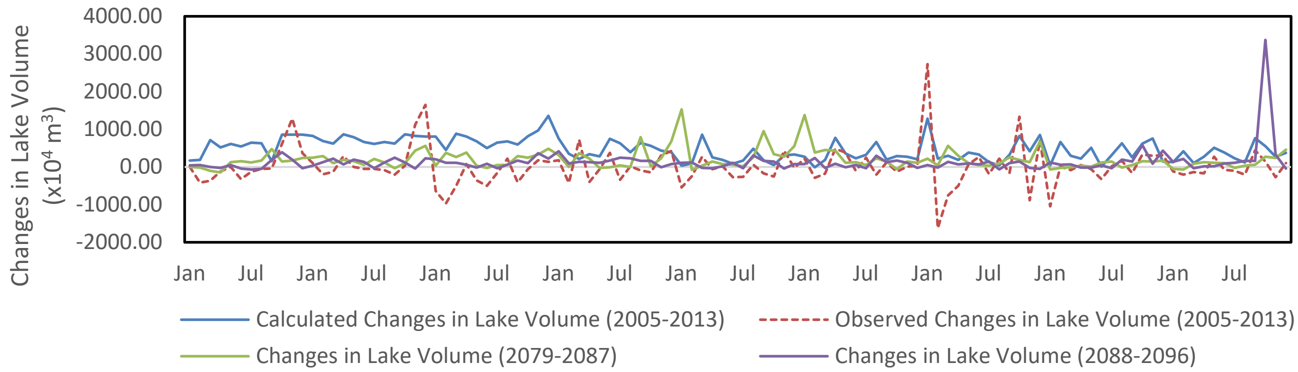
Figure 7: Components of Water Balance Model (a) Present (year 2003 to 2015), (b) Future (year 2079 to 2099)

4.1.3 Changes in Lake Volume

The analysis of the lake volume is indicated in Figure 8, (a) changes in lake volume considering all the components and (b) changes of lake volume consider only climate components. In order to balance the graph of present and future data, time range of the future data was taken from 2079-2096 only. In the condition (a), the value of future changes in lake volume is lower that the present value. While for condition (b), the pattern of future changes in lake volume almost the same with the present and above the zeroes value. For both condition, it shows that the future changes in lake volume in condition (b) is higher than in condition (a). The changes of trend between future and present in both condition is because the consideration of water intake and environmental flow in the water balance model. Where both of these components are the output value for the water balance model. When both of the components are taking out, is seems that the trend of the model is increasing.



(a)



(b)

Figure 8: Changes in lake volume (a) considering all components (b) considering only climate components

5.0 CONCLUSION

Based on the Water Balance Model, the trend of the lake volume for present and future water balance both shows a decreasing trend. This may be due to the decreasing value of precipitation and the increasing evaporation. Impact assessment of climate change around Asia has shown that in the future, approximately 15% of annual evaporation is increase.[12]

Changes in lake volume between observed and calculated shows similar trend, however, the scale of the changes could not be modelled perfectly. This might be due to the limitation in estimating the inflow from Sembrong catchment to the lake. Better estimation might be obtained using physical Rainfall-Runoff model. The effect of climate changes does not effect the lake volume. The future changes in lake volume is lower value compared to present changes.When value of water intake and environmental flow is not considered, the changes in lake volume is higher. Since the variability of the changes in lake volume small, the changes in lake volume for present and future considered to not having any significance difference. Here can be concluded that in the future, climate change did not really effect the lake volume and the condition of the dam in the future might not be critical.

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