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Climate Change Impact On Upper Layang Reservoir Operation

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Abstract

The goal of reservoir operation policies is to get the most out of the water that can be stored and delivered as a water supply. Water shortages and floods may become more common in Malaysia because of climate change and global warming. The biggest impediment to developing reliable water storage and supplies in Sg Layang Reservoir, Johor, Malaysia, is a lack of water. Forecasting reservoir water levels is critical for storage management, particularly in water supply systems. As a result, the objective of this research is to create a reservoir simulation model using the Hydrologic Modeling System (HEC-HMS) to generate water levels to compare with observed water levels and to predict water levels using input variables such as future daily rainfall to examine the reservoir's performance under changing conditions. Rainfall data from 2011 is utilized to calibrate the system, while data from 2012 to 2013 is used to validate it. The observed rainfall data was applied to the Sungai Layang watershed region. The correlation coefficient, R2, was employed to show the watershed's best value. The calibration procedure has an R2 of 0.91, whereas the validation procedure has an R2 of 0.88. The accuracy of the model is satisfactory, as the R2 is near to 1.0, and calibration parameters can be employed in the following design processes, according to the analysis completed by HEC-HMS applications. The simulation was carried out using the same parameters in 2017, 2030, and 2050 with four distinct scenarios to evaluate water level behavior using future rainfall data. According to the simulation, most of the water level in the future will be below the crucial threshold of 23.5m. The findings reveal that climate change has an impact on reservoir functioning in terms of rainfall intensity.

Keywords: climate change, reservoir, water level, water supply, hydrologic modeling system (HEC-HMS).

INTRODUCTION

Background

Reservoirs are well-known and effective structures for managing water resources that can be built (Allen et al., 2005). As a result, dams and reservoirs are key suppliers of surface water. It aids in the storage of water for human consumption. When inflows exceed outflows, the reservoir will restrict inflows and deliver outflows at a more regular rate, which will be decided by water demand. Reservoirs that are operated optimally can make full use of their storage capacity, maximizing economic advantages and preventing natural disasters like drought and flooding (Lin & Rutten,

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2016; Liu et al., 2011). Although there are many factors to consider and conflicting objectives, it is a challenging decision-making process. Climate change will undoubtedly make the process more challenging in the near future. The hydrological cycle and water resources are the most important aspects of changes in climatic situation. Alteration in climatic conditions will undoubtedly cause further complications in the near future. The hydrological cycle and resources concerned with water supply are the most important aspects of climate change. This is because hydrology and water essential elements closely related to the fields of industry, urban development, and economics. Climate change significantly affects water resources when there are changes to water bodies and water quality. The modifications may be brought on by climate variables, including temperature swings and rainfall amounts.

Many studies are accompanied since the growing influence concerned with change in climate on water resources. The public's high concern for the issue prompted scientists to start researching how climate change affects water supplies in the early 1980s. A study of the effects of climate change from 1985 to 1987 was published by the World Meteorological Organization (WMO), for instance, along with a number of testing and assessment techniques. Since the influence of climate change on water supplies has increased, there has been a lot of study done. The public prioritized the problem, which prompted researchers to begin studying how changes in climatic situation would impact water resources in the early 1980s. As an illustration, the World Meteorological Organization (WMO). The WMO then released an impact study report on climate change, which included a summary of the challenges in water resource systems because of future climate change (Houghton et.al., 1996; WMO, 1987).

Climate change uncertainty is currently wreaking havoc on reservoir performance when it comes to developing adaptive policies. Precipitation intensity and evaporation rate have the greatest impact on reservoir water volume, whereas transpiration and seepage are negligible contributors to the losses elements. (Allen et al., 2005), According to their findings, as the rate of evaporation increases, the bond between water molecules gains kinetic energy, resulting in the formation of water vapor, which then returns to the atmosphere. These activities are subject to significant losses, particularly if there is a big open water surface area, such as a reservoir.

This study will be placed in Sungai Loyang Reservoir. Sungai Layang's catchment area is one of the areas that has emerged because of the development of industry and society. This reservoir provides water to the residents of the surrounding area, which includes Johor Bahru. The Layang Reservoir is in Johor Bahru, near Masai. Upper Layang Reservoir and Lower Layang Reservoir are the two halves of the reservoir that can be split. Villages, plantations, and agricultural estates are the most common activities near the Layang River watershed. Water from the reservoir is most likely to be consumed in these regions.

The reservoir is currently troubled by a slew of issues, including increased water demands, which raises the risk of a water crisis. The low drizzle in the extent is one of the reasons for the water deficit, as the water level of Sungai Layang Reservoir is mostly affected by rainfall patterns within the catchment areas.

Sungai Layang Reservoir's water levels reached their lowest point in 2015 and remained critically low throughout the year (Ken, 2015; Musa, 2006). If this pattern continues, the reservoir will be unable to hold water for future supplies. The objective of this research is to create a reservoir simulation model using the Hydrologic Modeling System (HEC-HMS) to generate water levels to compare with observed water levels and to predict water levels using input variables such as future daily rainfall to examine the reservoir's performance under changing conditions. Rainfall data from 2011 is utilized to calibrate the system, while data from 2012 to 2013 is used to validate it. The observed rainfall data was applied to the Sungai Layang watershed region.

Methodology

This research is conducted utilizing hydrologic modeling to depict the impact of climate parameters, such as rainfall data, on reservoir functioning, such as reservoir water levels. It

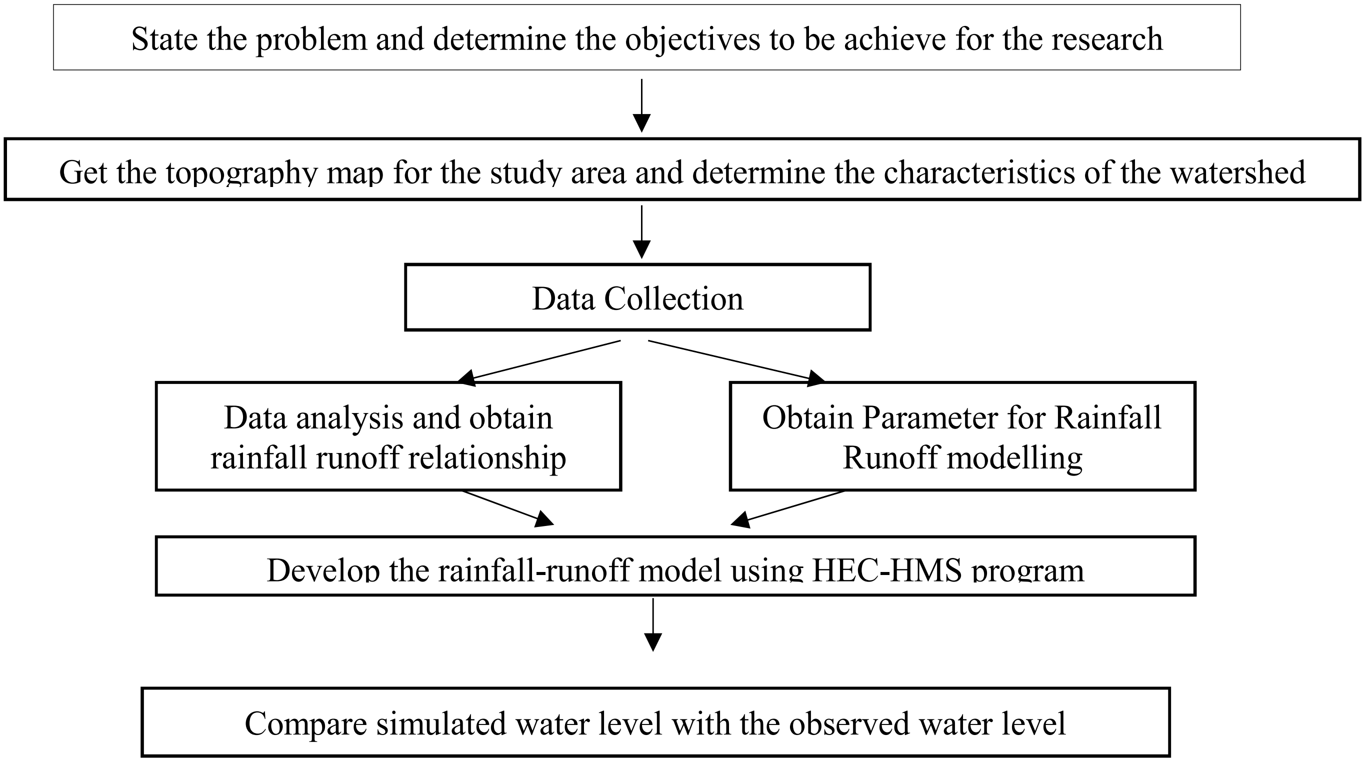

Figure 1 shows the flow chart in conducting this study.

investigated the relationship between the two variables. Climate variables from a general circulation model (GCM) were selected to match a specific emission scenario. These data were used to forecast precipitation for future years and were fed into a climate-change-aware hydrologic model. The overall study approach is depicted in Figure 3 as a flow chart.

3.1 HEC-HMS Software

To obtain a good and logical interpretation of the data, the usage of HEC-HMS for modelling and simulation in this study should be done in a systematic manner. A few procedures or processes in the HEC-HMS have been determined for the implementation of this study.

3.3.1 Basin Modelling Components

Hydrological limits for a study area are simulated using the HEC-HMS modeling components. Meteorologic Model, Control Specification, and Basin Model are the three components.

3.3.2 Gauge Data

Precipitation gauge data and discharge data are two types of gauge data required by HEC-HMS software when researching the rainfall-runoff relationship (discharge gauge). Precipitation data is required to estimate total runoff, whereas discharge data is necessary to calculate reservoir intake and outflow.

3.3.3 Loss, Transform and Baseflow Method

The model employs the initial and constant-rate loss technique, which can be utilized with any transform method. The percentage of soil erosion and soil type determine the initial loss and constant rate. The Manual Saliran Mesra Alam Malaysia (MASMA) recommends a value for this initial loss and constant rate. Clark Unit Hydrograph was utilized as the transform technique, while the constant-monthly approach was employed as the baseflow method. Initial Loss, Constant Loss Rate, Impervious, Storage Coefficient, and Time Concentration for each sub-basin are the factors used to determine losses in this study.

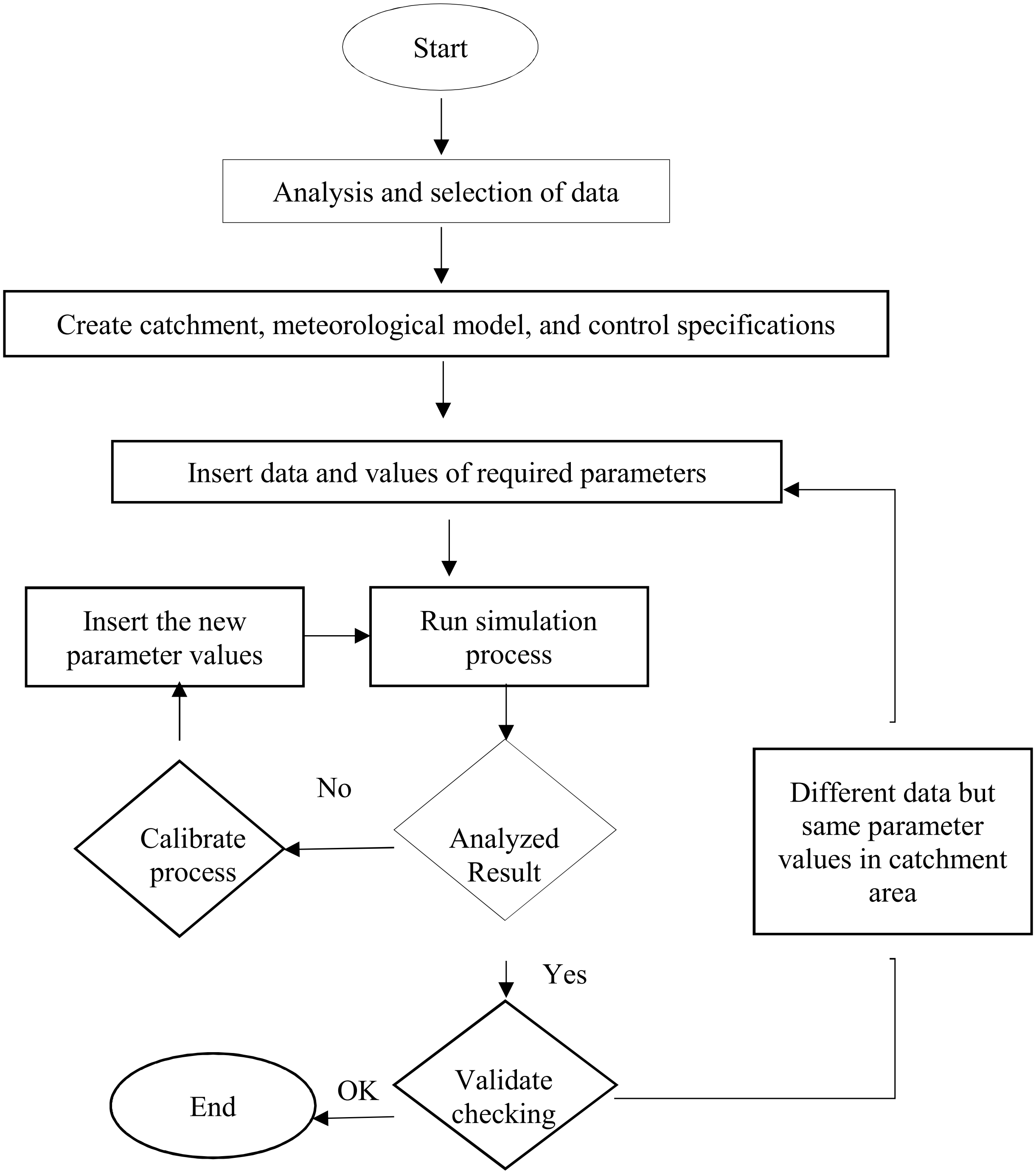

Figure 2: Flow of HEC-HMS simulation process

3.3.4 Model Performance Analysis

Four separate statistical performance criteria were computed in this work, together with a visual evaluation of model fits, to measure the agreement between observed and predicted flow in calibrations and validations. The statistical performance criteria considered are a) Nash Sutcliffe Efficiency (R2), b) Mean Error (Bias), c) Dimensionless Mean Error (ME/q), and d) Root Mean Square Error (RMSE). The criteria can be calculated as:

a) Nash Sutcliffe Efficiency,

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(Q_{o,i} - Q_{s,i})^2}{\sum_{i=1}^{N}(Q_{o,i} - \overline{Q_o})^2}$$

b) Mean Error (Bias),

$$ME = \frac{\sum_{i=1}^{N}(Q_{o,i} - Q_{s,i})}{N}$$

c) Dimensionless Mean Error,

$$\frac{ME}{\overline{Q}_o} = \frac{\sum_{i=1}^{N}(Q_{o,i} - Q_{s,i})}{N\overline{Q}_o}$$

d) Root Mean Square Error

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Q_{o,i} - Q_{s,i})^2}{N}}$$

Where,
Qo = Observed water level
Qs = Simulated water level
Q = Average observed water level
N = Number of data

Study Area

Sg. Layang is in Johor's south-western region. The Upper Sg. Layang watershed and the Lower Sg. Layang catchments are the two catchments that make up the Sg. Layang catchment. It is generally bordered by the scopes of 1°30' N and 1°36' N, and the longitudes of 103°50' E and 104°00' E, with heights extending from 30m to 160m over cruel ocean level. The reservoir is located 6 kilometers upstream from the mouth of the Sg Layang River in the Upper Layang watershed, which covers a total catchment area of 36.8 kilometers. This reservoir is in Masai, some 40 kilometers from Johor Bahru, and provides water for both domestic and industrial purposes. The reservoir

is managed by SAJ. The surface runoff from a 19.5km2 area downstream to the Upper Layang reservoir is solely received by the Lower Layang watershed. On the east side of the Upper Layang Reservoir is Lower Layang Reservoir. Hilir Layang Reservoir has a 20.5 km2 drainage basin.

4.1 Calibration of Model and Process of Validation

The HEC-HMS modeling technique has the advantage of generating optimal parameter values based on watershed characteristic data. Parameter values can be established using trial and error methods using the calibration procedure. This is the most significant phase since the parameters collected are the major results that will be used in the catchment area modeling process. The optimum constant parameters derived from the calibration method are shown in Tables 1 and 2.

Map of

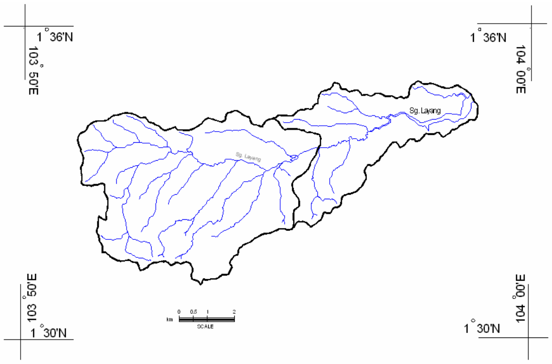

Figure 1:
Map of the study area

Outcome Interpretation and Discussion

Parameter	Value
Initial Loss (mm)	10
Consistent Rate (mm/hr)	20
Resistant (%)	25
Concentration Duration (hr)	24
Coefficient of Storage (hr)	40

Table 1: Summary of parameters used in hydrological modeling

Month	Flow (m^3/s)	Month	Flow (m^3/s)	Month	Flow (m^3/s)
January	0.50	May	0.44	September	0.50
February	0.44	June	0.36	October	0.28
March	0.40	July	0.39	November	0.60
April	0.43	August	0.45	December	0.65

Table 2: Base flow rates value

The outcomes of the validation process, which employed data from 2012 to 2013, are shown

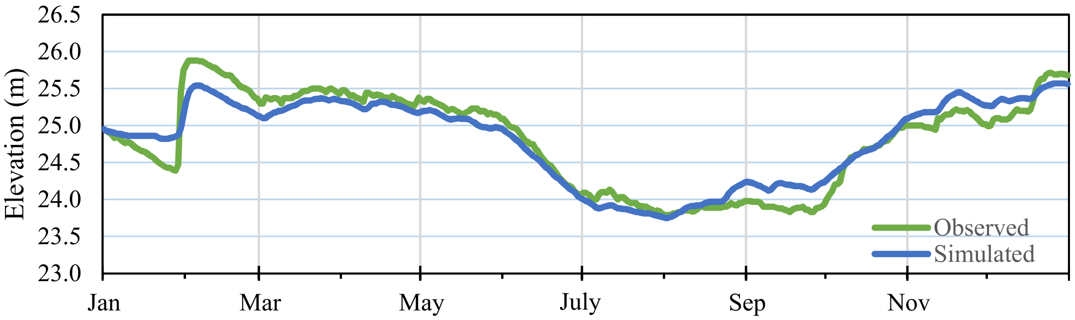

Figure 4: Simulated (blue) and observed (green) water level for calibration

in Figure 5. The result demonstrates that a storage coefficient parameter value of 40 hours is appropriate for generating future simulated water levels.

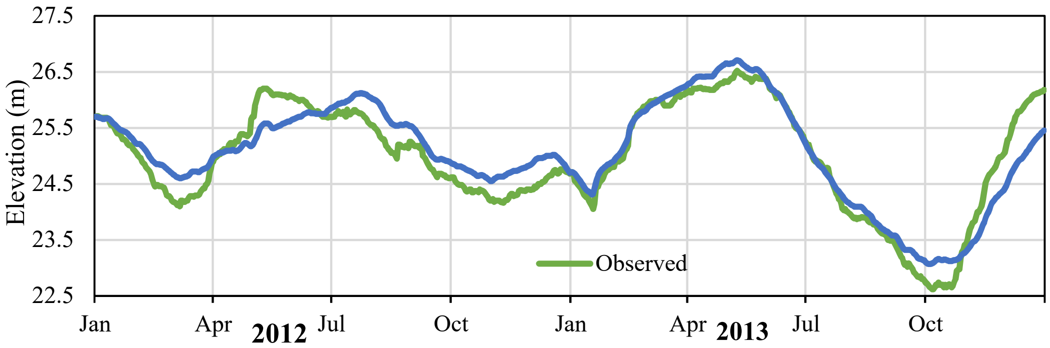

Figure 5: Simulated (blue) and observed (green) water level for validation

The difference in the results of statistical performance requirements for water level calibration and validation is shown in Table 3. The results of the two processes were compared using a model performance analysis formula.

4.2 Model Performance Analysis

The effectiveness of the created model was tested using Model Performance Analysis. It is required for both the calibration and validation processes to determine whether the parameters set in the modelling are appropriate. If the disparities between the simulated and observed results were significant, the model should not be used in such research or simulations in the future. The NSE, Mean Error, Dimensionless Mean Error, and RMSE methods were used to do the model performance study.

Method		Calibration	Validation
Nash Sutcliffe Efficiency	R^2	0.91	0.87
Mean Error (Bias)	ME	0.005	-0.09
Dimensionless Mean Error	ME/Q_o	0.00022	-0.0036
Root Mean Square Error	RMSE	0.193	0.341

Table 3: Model performance analysis result.

Notes :
R2 : Best = 1
ME : Best = 0
ME/Qo : Best = 0
RMSE : Best = 0, but it can be accepted if the calibration value is smaller than validation.

4.3 Results of current and future (2016, 2030 and 2050).

4.3.1 Rainfall Distribution

Figure 6 shows the rainfall intensity for 2016, 2030 and 2050 that was used to simulate water level in the reservoir. The data was used to assist the comparison between simulated water levels in current and future climates. Table 4 summarizes the rainfall data to see the differences in rainfall distribution within the year.

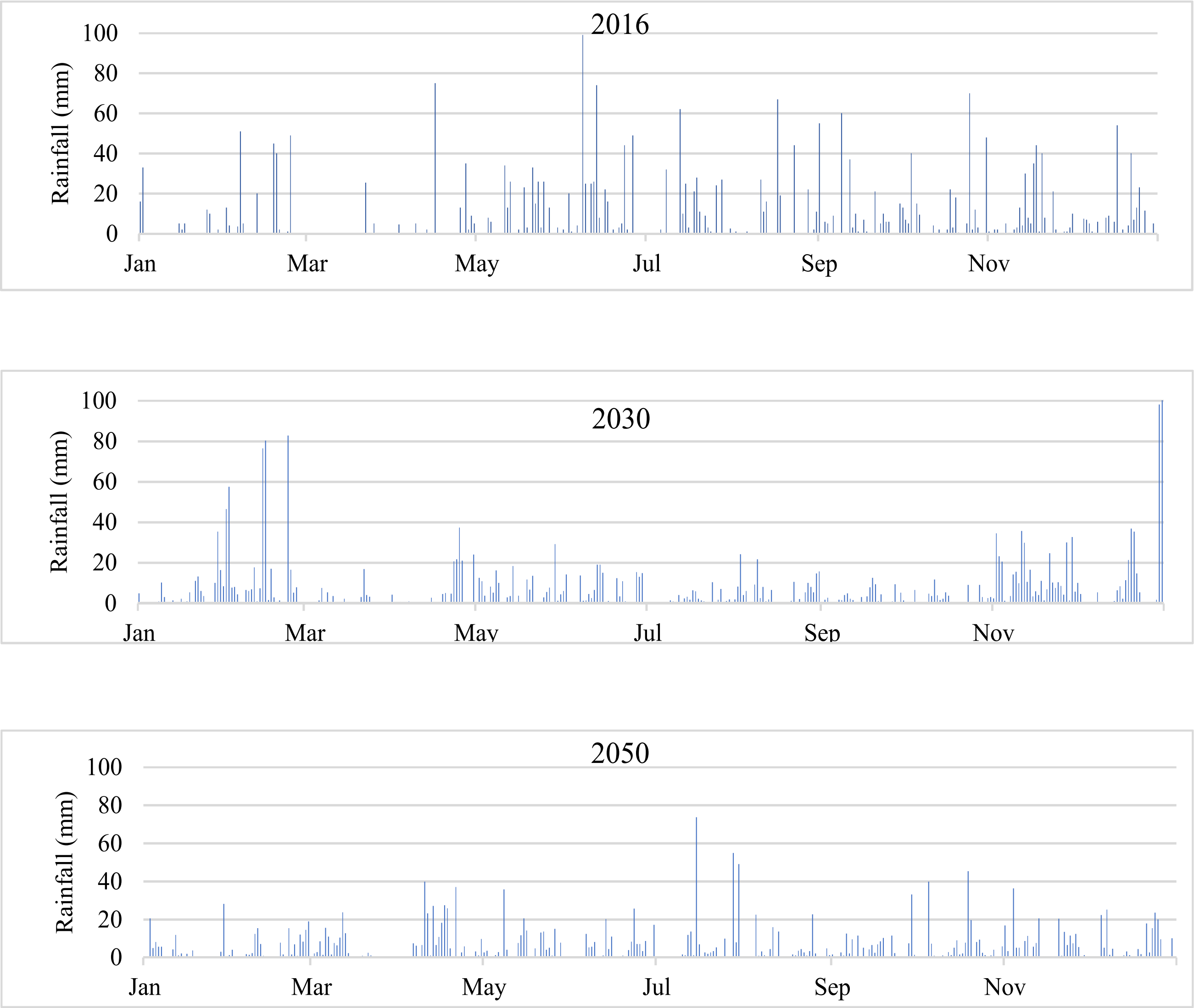

Figure 6: Rainfall intensity for 2016, 2030 and 2050

	Monthly Rainfall (mm)				Monthly Rainfall (mm)		
	2016	2030	2016		2016	2030	2050
January	85.00	135.45	106.66	July	260.50	53.31	249.29
February	233.50	464.17	137.01	August	221.00	168.12	111.54
March	30.50	50.38	112.63	September	257.00	79.38	142.55
April	150.50	148.94	266.7	October	281.00	72.31	179.35
May	234.00	178.08	170.81	November	231.00	385.07	202.36
June	427.00	176.09	150.35	December	219.00	366.95	172.64
Maximum Rainfall (mm)	99.00	101.30	73.76	Total Annual Rainfall (mm)	2630.00	2278.25	2001.89

Table 4: Summary of rainfall in 2016, 2030 and 2050

Scenario		S1[1]			S2[2]		
Year		2016	2030	2050	2016	2030	2050
Elevation (m)	Min	21.3	20.2	19.87	20.65	13.67	13.66
	Date	14-Apr	28-Oct	11-Jul	15-Apr	9-Oct	5-Oct
	Max	27.47	22.05	21.01	22.14	-	-
	Date	31-Dec	28-Feb	31-Dec	26-Nov	-	-
Scenario		S3[3]			S4[4]		
Year		2016	2030	2050	2016	2030	2050
Elevation (m)	Min	13.75	13.76	13.68	13.7	13.73	13.66
	Date	30-Apr	13-Apr	8-Apr	18-Apr	3-Apr	25-Mar
	Max	-	-	-	-	-	-
	Date	-	-	-	-	-	-

4.3.2 Simulated water level in reservoir for 2016, 2030 and 2050.

*Notes:
1S1 = with both raw water transfer
2S2 = water Transfer from Sg. Johor only
3S3 = water Transfer from Lower Layang only
4S4 = without both raw water transfer

The water level varies in each condition, as illustrated in Table 5. In Scenario 1, there are maximum and lowest water levels for each year since the reservoir storage has constant input and outflow. On December 31, 2016, the maximum water level was 27.47 meters, and on April 14, the lowest water level was 21.3 meters. Figure 6 shows that the absence of rainfall intensity in March and April 2016 may have contributed to the decreased water level. Because the rainfall intensity was continuous for a very long time, the inflow was greater than the outflow, causing the water level to rise over time. For the projected predicted water level in 2030, the maximum and lowest water levels will be 22.05m and 20.2m, respectively. These results may have been influenced by high rainfall intensity in February 2030 and a long period of low rainfall intensity from July to October 2030. Based on rainfall intensity values of 21.01m and 19.87m, the highest and lowest water levels were reached in 2050. Overall, the findings show that water levels have been steadily decreasing over time. This is related to a drop in rainfall intensity, as shown in Table 4. Scenario 2 indicates that the reservoir's water level is still steady, increasing and decreasing in response to rainfall intensity, even though the value is below the crucial level of 23.50m. The findings revealed that the reservoir could still hold water in 2016. However, in the future, when one of the water transfers is missing, the reservoir will be unable to store water since the outflow will be greater than the intake. In 2030, the reservoir will begin to dry on the 9th of October, and on the 5th of October in 2050. The findings revealed that the length of water retained in reservoirs is affected by climate change. The reservoir was anticipated to dry down faster in 2050 than it did in 2030. It will be demonstrated if the rainfall in 2050 is lower than in 2030. Scenarios 3 and 4 are only slightly different since Scenario 3's average water transfer rate from Lower Layang is just around 0.5m3/s, but Scenario 4 does not allow any water transfer into the reservoir. However, in Scenario 4, the reservoir dries out earlier in all years than in Scenario 3. It also demonstrates that water transfer is important in ensuring that the reservoir runs smoothly. Water from the catchment alone will not be sufficient to meet water demand. Climate change will have an impact on reservoir operating in the future when the time for the reservoir to dry is earlier than it is now. The most surprising finding is that the reservoir is anticipated to dry out at a critical period.

Conclusion

The hydrological simulation was successfully built using HEC-HMS with the following parameters: starting loss 10mm, constant rate 20mm/hour, impervious 25%, concentration time 24 hours, and storage coefficient 40 hours, according to the results obtained and observations made in the research study. The hydrologic model was standardized and authorized with R2 coefficients of 0.91 and 0.87. The outcome was acceptable because it was close to 1.0. Four different future scenarios were used to precisely forecast the water level, all of which were below the critical limit of 23.5 meters. This means there is a potential water shortage that will happen again in the future. In the future, water transmission will be even more crucial than it is now.

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