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Study of Tiu Kulit Dam Reservoir Operational Pattern Simulation in Sumbawa Island

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ABSTRACT

Tiu Kulit Reservoir plays a pivotal role in managing water resources in West Nusa Tenggara, Indonesia, serving as a vital source for raw water, irrigation, and livestock consumption in the neighboring regions. This study aims to assess the operational dynamics of Tiu Kulit Reservoir across varying hydrological conditions, namely dry, normal, and wet years. The analysis is based on inflow rates and equilibrium water surface elevations. To achieve the objectives, an investigation of the reservoir's operation pattern was conducted. Inflow rates and equilibrium water surface elevations were scrutinized to discern operational behaviors under different hydrological scenarios. The findings indicate distinct operational strategies for Tiu Kulit Reservoir. During dry years, the outflow rate is restricted to 1.20 m^3/s at a water surface elevation of +53.07 m. Conversely, the reservoir's operation in normal and wet years allows for a maximum outflow rate aimed at satisfying water demand, set at +57.00 m. In instances of excessive rainfall, the study highlights the potential for overflow beyond the spillway threshold. The study underscores the significance of these results for effective water management and resource allocation in the region. Understanding the reservoir's behavior under various conditions enables informed decision-making and sustainable utilization of water resources. To build upon this study, it is recommended to implement continuous monitoring systems for both inflow and outflow rates. Furthermore, the installation of rainfall monitoring stations within the catchment area would enhance data accuracy. Regular evaluations of the reservoir's operational patterns are also advised, allowing for adaptive strategies in response to evolving climate conditions. Moreover, future research endeavors should focus on augmenting water supply to meet the demands of a growing population and livestock, while optimizing agricultural practices to boost productivity.

1. Introduction

Reservoirs play an important role for water resources management by helping store rainwater received from their drainage areas and regulate downstream streamflow. Reservoir operation can alter downstream flow regimes and ecosystems [1]–[3]. In reservoir construction, the part that is most concerning is the analysis of its production and capacity. The production is the amount of water that can be provided by the reservoir in a span of time. From the planned reservoir production, it can be determined how much reservoir capacity is needed to be able to meet the demand with a certain reliability. It is used for reservoir planning purposes.

Tiu Kulit Dam is a dam located in Simu Village, Maronge District, Sumbawa Regency, West Nusa Tenggara. By 2020, Tiu Kulit Reservoir will have an effective storage of approximately 7,15 million m3. Water storage utilization in Tiu Kulit Reservoir is to meet the needs of raw water for 640 households, irrigation water for 1512 ha of rice fields, and drinking water for 600 livestock. This needs fulfillment is the basis of the optimization study of the Tiu Kulit Reservoir's operational pattern.

An increase in the water level of the reservoir can have various impacts [4], [5]. During periods of high rainfall, it will undoubtedly affect the amount of water received by the reservoir, potentially causing the water level to exceed its normal limits. This can result in water overflow and flooding, with a significant risk of dam breach, especially if the geological conditions around the dam are unable to withstand the pressure from the rising water surface. Similarly, a decrease in the water surface level of the dam reduces the available water supply. Therefore, there is a need for an

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optimal reservoir operation pattern to prevent potential issues.

For operational purposes, the correlation between capacity and production is defined as the amount of demand that can be served per unit of time following the existing capacity. Studying the correlation between capacity and production is called an operational study. An operational study that can reveal the characteristics of the reservoir based on seasonal conditions and the diversity of needs requires a simulation. The reservoir operation simulation is used for a certain period based on established rules. In this study, aside from simulating the operational pattern of the reservoir, recommendations will also be given on problems that might occur in Tiu Kulit Reservoir. The pattern of water use operation is important to ensure the continuity of water supply system of a reservoir [6]–[8].

The objectives of this study are to determine the availability of water as an inflow for the Tiu Kulit Reservoir, to determine the discharge of water demand as an outflow for Tiu Kulit Reservoir, and to simulate Tiu Skin Reservoir in existing conditions, normal year, wet year, and dry year in order to get the operational pattern of the reservoir.

2. Method

Tiu Kulit Dam is located in Simu Village, Maronge District, Sumbawa Regency, West Nusa Tenggara, with the body of the dam located at coordinates 117°40'49.96" E and 8°41'19.82" S. The location of this dam is ± 48 Km from Sultan Muhammad Kaharudin III Airport and can be reached within ± 1 hour by using a four-wheeled vehicle. Tiu Kulit Dam is located on Bera Watershed as in Figure 1.

2.1. *Material*

The data used in this study include:

a. Reservoir characteristic data: Reservoir storage capacity; Reservoir elevation and water level
b. Hydrological data for reservoir outflow: Rainfall data from Plampang Station and Pungkit Atas Station for 1996 – 2018; Climatological data from Plampang Station and Pungkit Atas Station for 1996 – 2018; Secondary data related to the water used for land irrigation purposes; The number of heads of the families data in the Tiu Kulit Reservoir service area; The number of livestock data in the Tiu Kulit Reservoir service area

2.2. *Methods*

2.2.1. *Stages of Study Completation*

a. Data Collecting: The required data include the characteristics of the reservoir, rainfall data from 1996 to 2018, climatological data, water usage data, number of households data, and livestock data.
b. Determination of Regional Rainfall: Using data from Plampang and Pungkit Atas Rain Stations on 1996 – 2018 to get rainfall value in Tiu Kulit Dam area with Regional Average Rainfall method.
c. Statistics Analysis: Using rainfall data for Tiu Kulit Dam DPS area to determine whether the selected data can be used for further analysis.
d. Effective rainfall analysis: Using rainfall data in Tiu Kulit Dam DPS area to determine irrigation water need.
e. Rainfall transformation into discharge: Using rainfall data in Tiu Kulit Dam DPS area for the analysis of reliable discharge which serves as an inflow with FJ Mock method.
f. Dependable Flow Calculation: Using FJ Mock flow as inflow discharge in storage simulation with Basic Year method.
g. Potential Evapotranpiration Analysis: Using rainfall data in Tiu Kulit dam area and climatology data with Penman Modification method as one of the parameters in determining irrigation water need.
h. Water needs and water supply analysis: Using the availability data and water demand with water balance analysis.
i. Reservoir storage simulation: Using reservoir capacity, inflow discharge, outflow discharge, and reservoir water surface evaporation to get the result of operational pattern.
j. Rule curve: Reservoir operational pattern result used as guideline for the reservoir operation.

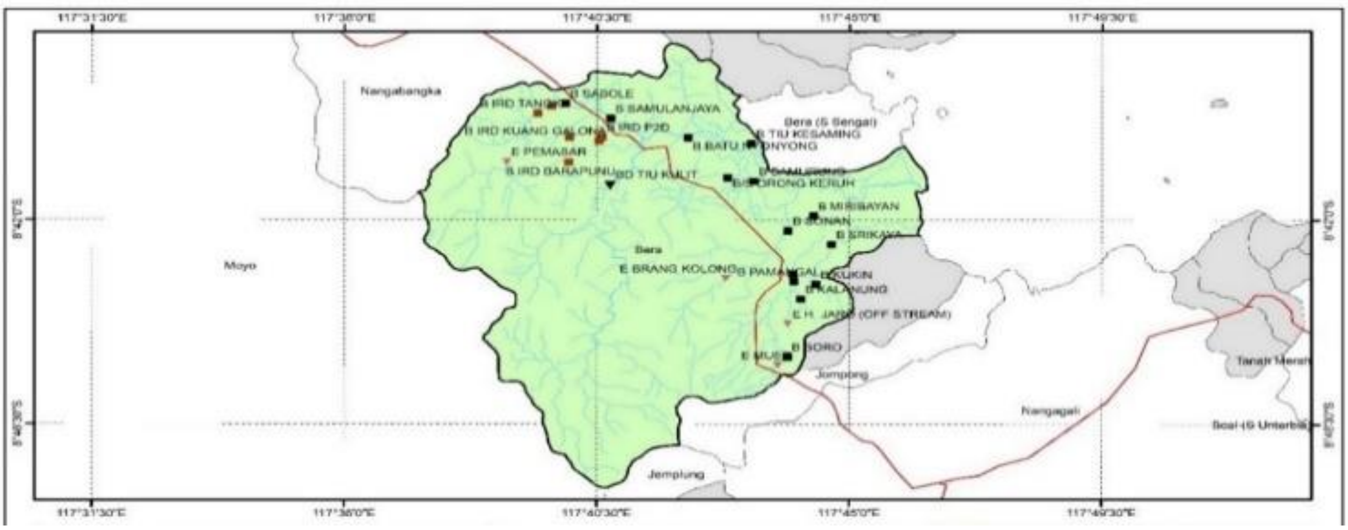

Figure 1. Bera Watershed Map

2.2.2. *Water Supply Analysis*

The availability of discharge in the Tiu Kulit Dam is expressed as the dependable flow, where the calculation of the dependable flow is determined using the Basic Year method, which involves taking a certain flow pattern from a particular year. The probability of its occurrence is then calculated using the Weibull formula as following Eq (1) [9].

$$P = \frac{m}{n+1}.100\% \qquad (1)$$

Where: P = Probability (%); M = data serial number; n = number of events

2.2.3. *Reservoir Storage Capacity Curve*

The reservoir storage capacity curve is a curve that describes the correlation between the water surface area (reservoir area), volume (storage capacity) and elevation (reservoir water level). From the reservoir capacity curve, it will be known how much the storage is at a certain elevation so that the water level required to get the volume of the reservoir at a certain elevation can be determined. From the high capacity arch equation, the water level of the reservoir can be determined by the Eq (2).

$$H = Ch.S^{0.5} \qquad (2)$$

where: H = water level of the reservoir (m); S = total storage volume (m^3); Ch = correlation coefficient

If losses are taken into account, this loss is multiplied by the area to get the volume of loss. The curved equation for the capacity of the reservoir area can be stated as follows Eq (3).

$$A = Ca.S^{0.5} \qquad (3)$$

Where: A= water surface area (km^2); S = total storage volume (m^3); Ca = correlation coefficient

The storage capacity of an irregularly shaped reservoir can be calculated using the formulas used to calculate the volume of solids. The reservoir capacity at its natural position must usually be determined based on topographical measurements [6], [9]. This calculation is based on a map with a scale of 1: 1000 and a height difference of 1-meter contour. Find the surface area of the inundated small dam bounded by the contour lines. Then find the volume bounded by two consecutive contour lines using the volume approximation Eq (4) [10].

$$Vx = \frac{1}{3}xZx\left(Fy + Fx + \sqrt{Fy + Fx}\right) \qquad (4)$$

Where: Vx = Volume on the contour (m^3); Z = Height differences between contours (m); Fy = area on the contour Y (m^2); Fx = Area on the contour X (m^2)

From the above calculations, a graph of the correlation between elevation, volume and the area of the volume of the reservoir can be found at a certain elevation.

The graph of the correlation between elevation with reservoir volume and reservoir area on Figure 2.

In the situation or analysis of the operational behaviour of a reservoir, the aim is to determine changes in the reservoir's storage capacity. The equation used is the mass storage equation, which provides a relationship between input, output, and changes in storage [11]. The mathematical equation is stated as following Eq (5).

$$St + 1 = St + Qt - Dt - Et - Lt$$
$$0 <= St+1 <= C \qquad (5)$$

Where; t = time interval used; St = reservoir storage at the beginning of the time interval; St+1 = reservoir storage at the end of the time interval; Qt = inflow during the time interval t; Dt = outflow during the time interval t; Et = evaporation during the time interval t; Lt = other water losses from the reservoir during the time interval t; it has a small value and can be neglected; C = effective storage

Storage capacity must be able to guarantee water supply with 100% reliability of fulfilment.

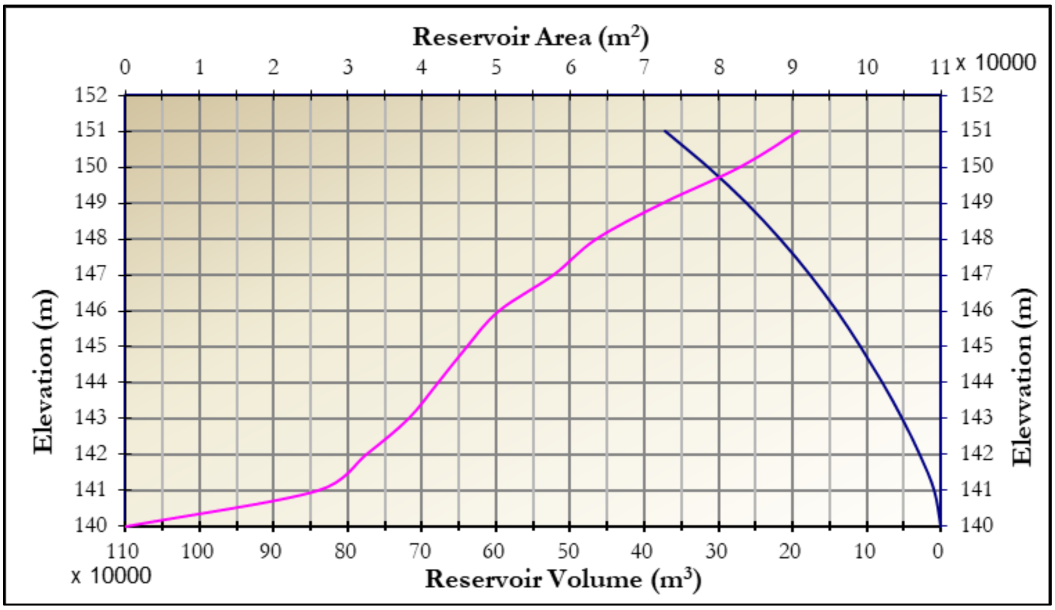

Figure 2. The graph of the correlation between elevation with reservoir volume and reservoir area

2.2.4. *Simulation of Irrigable Land Area*

Taking into account the inundation area of the reservoir, which varies with time, the equation is further written as following Eq (6) [11].

$$St + 1 = St + Qt + Rt(A) - Ot - Et - Pt - SPt(A) \quad (6)$$

Where: Rt(A) = rain that falls into the reservoir at time interval t, as a function of the surface area of the reservoir; Ot = reservoir withdrawal during the interval from t; Et(A) = evaporation over a time interval t, as a function of surface area in the reservoir; Pt = overflow that passes through the spillway during the time interval t; SPt(A) = seepage out of the reservoir during time intervals; as a function of the surface area of the reservoir water has a small value and can be neglected.

2.2.5. *Rule Curve*

In the reservoir operation pattern where the discharge is based on the reservoir storage status, limitations are imposed on the discharge when the reservoir storage decreases [12]. To determine the percentage of meeting needs, the discharge (%) can be replaced using a solver in Microsoft Excel. The process is done as follows:

a. Determine the reservoir storage interval (%): In this study, a 10% interval is used for the reservoir storage.
b. Using solver, the minimum spill-out criteria, reliability >= 80%, and the condition of the final reservoir storage at the end of the full period are entered.
c. It is expected that the spill-out is minimized to be utilized as efficiently as possible.
d. Create a table of ranges, minimum reservoir storage limits (%), and discharge (%).

3. Result and Discussion

3.1. *Rainfall Analysis*

The regional rainfall for the Tiu Kulit Dam is determined by taking the average rainfall between the Plampang Station and the Upper Pungkit Station, which resulted in an annual average rainfall of 1,835 mm for the Tiu Kulit Dam in DPS. Furthermore, the regional rainfall for the Tiu Kulit Dam, which will be used as the basis for further analysis. The recapitulation of rainfall data can be seen on Table 1.

3.2. *Water Supply Analysis*

By using F.J Mock's rainfall-runoff modeling, a 15-day period reliable discharge is obtained for each probability (P) [13]–[18] at the Tiu Kulit Dam as **Figure 3** and **Figure 4**.

3.3. *Water Demand Analysis*

3.3.1. *Irrigation Water Demand*

The existing irrigation service area of the Tiu Kulit Dam is 1512 Ha. While the Cultivation Pattern applied is two times the planting period, namely Paddy - Paddy/Crops with a cropping intensity (CI) of 166% with details of 100% paddy in Planting Period I and for Planting Period II are Paddy and Palawija with an intensity of 44 % and 22%. The beginning of planting is the 1st of January, while the start of land preparation is the 1st of December. The result of calculating the need for irrigation water served by the Tiu Kulit Dam is 0.79 l/s/ha.

3.3.2. *Raw Water Demand*

The raw water demand is calculated based on the Operational Policy Table for Clean Water Program [19], and it is assumed that each resident in the service area of Tiu Kulit Dam has a small town category water demand, which is 130 litres/person/day of raw water demand.

Assuming that each household consists of 5 family members with total 640 households and 130 liters per person per day, the total raw water demand that Tiu Kulit Dam must serve is 416.000 liters/day or equals to 0,005 m^3/s.

3.3.3. *Livestock Drinking Water Demand*

The calculation of livestock drinking water requirements will use the most conservative estimate, which assumes that the livestock consists of cows, buffaloes, and horses with the highest water demand [20]. With a total livestock count of 600 head and the water requirement of 40 liter per animal per day, therefore, the total water demand for the livestock is 24.000 liters/day or equals to 0,0003 m^3/s. Preliminary Water Balance for Tiu Kulit Dam Inflow can be seen on **Figure 5**.

3.4. *Reservoir Storage Simulation*

As of the year 2020, Tiu Kulit Reservoir has an effective storage capacity of approximately 7.15 million m^3 at the Normal Water Level (NWL) of +57.00 m. Meanwhile, the reservoir's storage capacity at the Minimum Operational Level (MOL) of +41.80 m is 0.05 million m^3.

Table 1. Recapitulation of Rainfall Data

Year	Yearly Rainfall	Maximum Rainfall
1996	1,611	154.8
1997	1,545	154.8
1998	2,039	136.4
1999	2,294	135.5
2000	2,357	162.0
2001	1,741	126.0
2002	2,182	234.0
2003	2,258	200.0
2004	1,595	125.0
2005	1,652	150.0
2006	2,787	80.4
2007	1,317	60.0
2008	1,680	85.3
2009	1,689	179.5
2010	2,572	137.0
2011	1,407	96.7
2012	1,231	117.8
2013	2,420	98.0
2014	1,906	171.0
2015	1,013	62.9
2016	1,924	143.5
2017	1,640	115.6
2018	1,344	119.2

Civil and Environmental Science Journal
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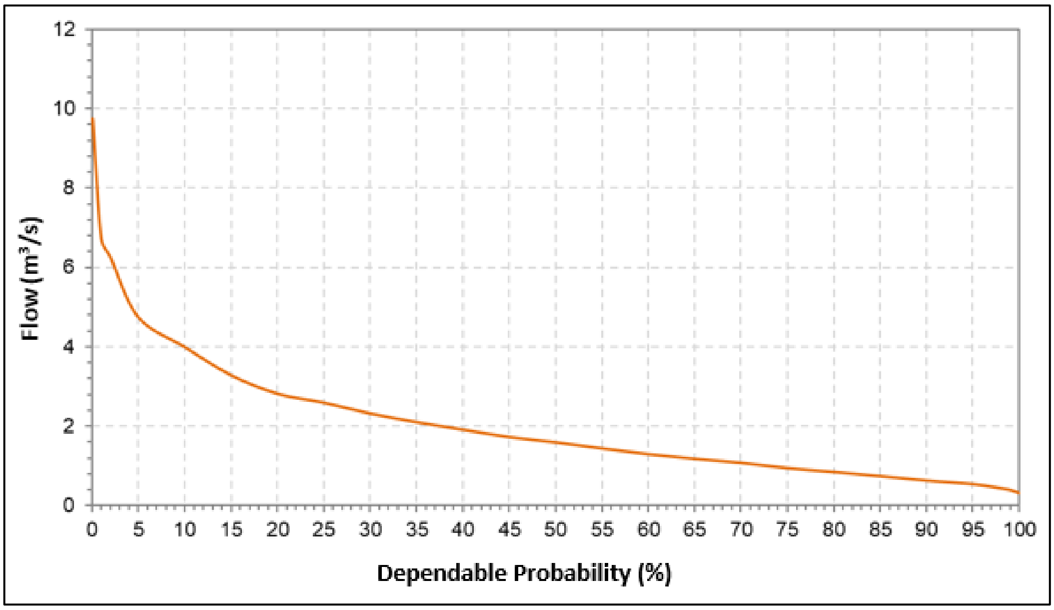

Figure 3. Tiu Kulit Dam Inflow Probability

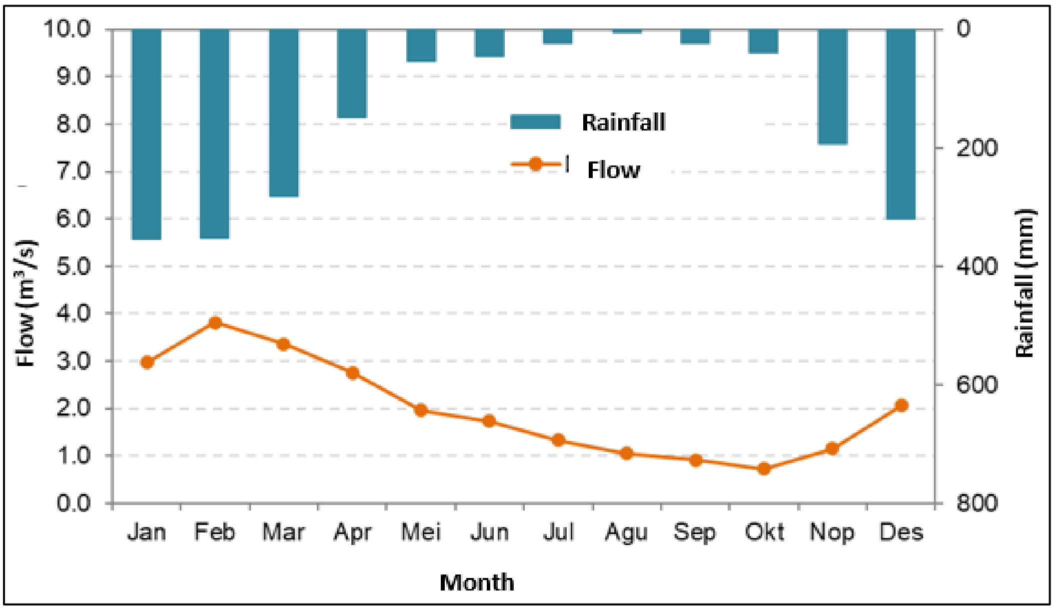

Figure 4. Tiu Kulit Dam Monthly Average Discharge Availability

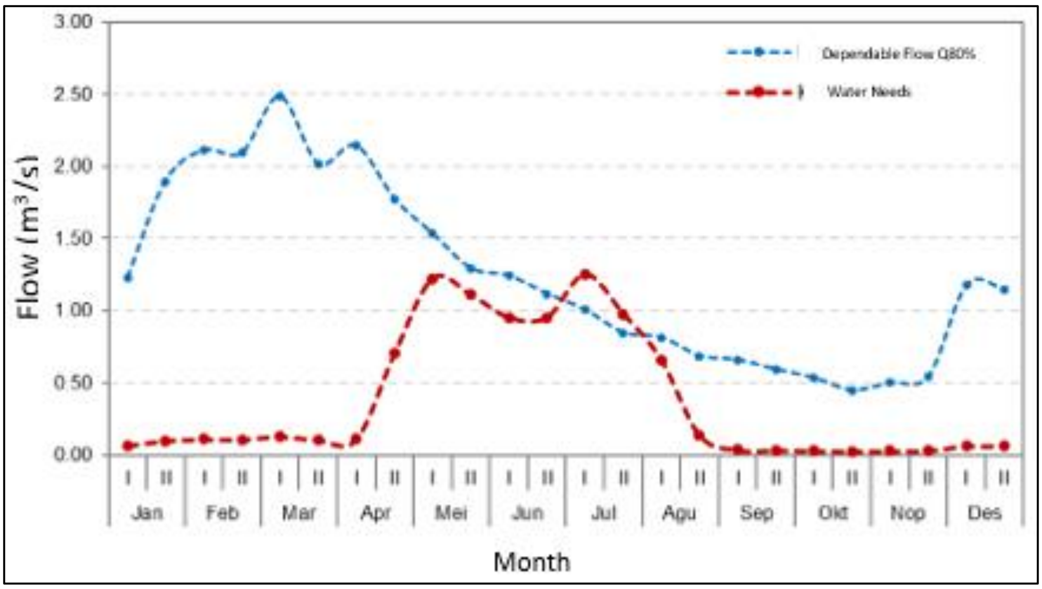

Figure 5. Preliminary Water Balance for Tiu Kulit Dam Inflow

Tiu Kulit Dam has an Ogee spillway type without gates, with a spillway width of 35.00 m and a spillway crest level at +57.00 m elevation. The dam is also equipped with an emergency spillway with a width of 25.00 m and a crest level at +60.00 m elevation, which is 3.00 m above the main spillway. Tiu Kulit reservoir ruling curve can be seen on Figure 6.

3.4.1. *Reservoir Inflow*

The determination of the operational pattern classification of the reservoir is based on the probability of the annual volume in sequence, where for dry years, it is determined at a volume percentage of 0 - 33.3%, for normal years at a volume percentage of 33.3% - 66.7%, and for wet years at a volume percentage of 66.7% - 100% as shown in Table 2.

3.4.2. *Reservoir Simulation Model*

The inflow data is relatively uniform, where there is a tendency for inflow to occur sequentially in the same year type, with the longest wet year period occurring from 2001/2002 to 2003/2004, normal year occurring from 2008/2009 to 2010/2011, and dry year occurring in 2006/2007; 2016/2017 to 2007/2008; 2017/2018 as shown in Table 3 and Table 4. The most critical condition that needs to be known is when there is a low inflow discharge for a long period in a dry year. In such conditions, the results of simulations need to be evaluated.

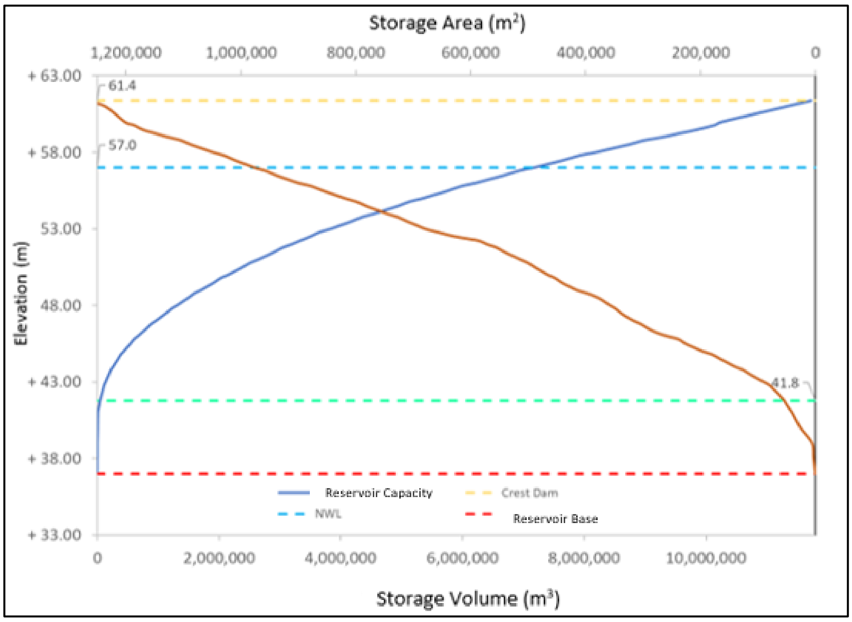

Figure 6. Tiu Kulit Reservoir Ruling Curve in 2020

Table 2. Volume Inflow of Tiu Kulit Reservoir Sorted by December I to November II Period

No	Year	Yearly Vol. (Mill. m³)	Year Type	Probability (%)	Sorted Year	Sorted Volume (Mill. m³)	Information
1	1996/1997	53.14	Normal	4.3%	2011/2012	38.11	
2	1997/1998	46.89	Dry	8.7%	2007/2008	41.79	
3	1998/1999	89.44	Wet	13%	2016/2017	41.84	
4	1999/2000	80.86	Wet	17.4%	2017/2018	42.38	Dry
5	2000/2001	65.28	Normal	21.7%	2014/2015	43.55	
6	2001/2002	78.48	Wet	26.1%	1997/1998	46.89	
7	2002/2003	88.02	Wet	30.4%	2006/2007	49.60	
8	2003/2004	78.83	Wet	34.8%	2015/2016	52.74	
9	2004/2005	54.02	Normal	39.1%	1996/1997	53.14	
10	2005/2006	89.88	Wet	43.5%	2004/2005	54.02	
11	2006/2007	49.60	Dry	47.8%	2010/2011	57.23	Normal
12	2007/2008	41.79	Dry	52.2%	2009/2010	63.31	
13	2008/2009	66.89	Normal	56.5%	2013/2014	64.37	
14	2009/2010	63.31	Normal	60.9%	2000/2001	65.28	
15	2010/2011	57.23	Normal	65.2%	2008/2009	66.89	
16	2011/2012	38.11	Dry	69.6%	2000/2001	78.48	
17	2012/2013	85.63	Wet	73.9%	2003/2004	78.83	
18	2013/2014	64.37	Normal	78.3%	1999/2000	80.86	
19	2014/2015	43.55	Dry	82.6%	2012/2013	85.63	Wet
20	2015/2016	52.74	Normal	87%	2002/2003	88.02	
21	2016/2017	41.84	Dry	91.3%	1998/1999	89.44	
22	2017/2018	42.38	Dry	95.7%	005/2006	89.88	

Table 3. The Water Level Elevation of Tiu Kulit Reservoir from Operation Simulation Results

Year	Water Level (m)																							
	Dec		Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
1996/1997	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.97	56.35	55.81	55.69	56.16	56.65	57.00	57.00	57.00	57.00	57.00
1997/1998	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.91	56.99	56.88	56.62	56.38	56.35	56.85	57.00	57.00	57.00	57.00	57.00	57.00
1998/1999	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
1999/2000	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2000/2001	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.69	56.44	56.58	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2001/2002	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2002/2003	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2003/2004	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2004/2005	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.87	56.78	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2005/2006	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2006/2007	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.99	56.39	55.87	55.78	56.25	56.75	57.00	57.00	57.00	57.00	57.00
2007/2008	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.83	56.48	56.32	56.01	55.05	54.15	53.77	54.10	54.49	54.78	54.98	55.05	55.39	57.00
2008/2009	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.77	56.60	56.81	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2009/2010	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2010/2011	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.86	56.89	56.74	56.02	55.35	55.14	55.54	56.00	56.33	56.57	56.69	57.00	57.00
2011/2012	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.43	55.71	55.19	54.48	53.04	52.53	50.62	50.77	51.10	51.29	51.37	51.31	51.24	53.07
2012/2013	54.65	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2013/2014	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.69	56.45	56.59	57.00	57.00	57.00	57.00	57.00	57.00	57.00
2014/2015	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.85	56.53	56.39	56.09	55.16	54.29	53.93	54.26	54.67	54.97	55.16	55.24	55.30	55.30
2015/2016	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.56	56.20	56.24	56.81	57.00	57.00	57.00	57.00	57.00	57.00
2016/2017	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.83	56.83	56.65	55.90	55.20	54.97	55.35	55.80	56.13	56.35	56.47	56.88	57.00
2017/2018	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.63	56.10	55.76	55.26	54.08	52.94	52.33	52.58	52.95	53.19	53.33	53.34	53.34	56.82
Wet year A	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
Normal Yeary	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.99	56.70	56.46	56.54	56.86	56.97	57.00	57.00	57.00	57.00	57.00
Year Avg	56.66	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.82	56.49	57.00	56.02	55.08	54.18	53.78	54.11	54.52	54.81	54.97	55.02	55.16	56.17
Avg WL El.	56.89	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.94	56.84	57.00	56.68	56.28	55.91	55.81	56.03	56.20	56.30	56.35	56.37	56.42	56.74
Max WL El.	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
Min WL El.	54.65	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.43	55.71	57.00	54.48	53.04	51.53	50.62	50.77	51.10	51.29	51.37	51.31	51.24	53.07

Table 4. The Probability of Water Level Elevation of Tiu Kulit Reservoir from Operation Simulation Results

Probability	Water Level (m)																							
	Dec		Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
4.3%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
8.7%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
13%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
17.4%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
21.7%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
26.1%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
30.4%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
34.8%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
39.1%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.87	56.78	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
43.5%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.77	56.60	56.81	57.00	57.00	57.00	57.00	57.00	57.00	57.00
47.8%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.69	56.45	56.59	57.00	57.00	57.00	57.00	57.00	57.00	57.00
52.2%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.69	56.44	56.58	57.00	57.00	57.00	57.00	57.00	57.00	57.00
56.5%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.62	56.38	56.35	56.85	57.00	57.00	57.00	57.00	57.00	57.00
60.9%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.99	56.56	56.20	56.24	56.81	57.00	57.00	57.00	57.00	57.00	57.00
65.2%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.97	56.39	55.87	55.78	56.25	56.75	57.00	57.00	57.00	57.00	57.00
69.6%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.91	56.99	56.88	56.35	55.81	55.69	56.16	56.65	57.00	57.00	57.00	57.00	57.00
73.9%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.86	56.89	56.74	56.02	55.35	55.14	55.54	56.00	56.33	56.57	56.69	57.00	57.00
78.3%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.83	56.83	56.65	55.90	55.20	54.97	55.35	55.80	56.13	56.35	56.47	56.88	57.00
82.6%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.85	56.53	56.39	56.09	55.16	54.29	53.93	54.26	54.67	54.97	55.16	55.24	55.39	57.00
87%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.83	56.48	56.32	56.01	55.05	54.15	53.77	54.10	54.49	54.78	54.98	55.05	55.30	56.82
91.3%	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.63	56.10	55.76	55.26	54.08	52.94	52.33	52.58	52.95	53.19	53.33	53.34	53.34	55.30
95.7%	54.65	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	56.43	55.71	55.19	54.48	53.04	51.53	50.62	50.77	51.10	51.29	51.37	51.31	51.24	53.07

3.5. *Reservoir Storage Simulation*

Based on the evaluation results through the simulation of the reservoir water level operation towards inflow and outflow discharge according to the existing conditions, it is known that there is no deficit in all categories of operational years, whether it is dry, normal or wet years (Figure 7). Therefore, the regulation of outflow discharge for all categories of years is the same, which is based on the current maximum needs (100%).

3.6. *Discussion*

In this study, Tiu Kulit Dam was completed in 1991 but only started operating in 1994. Therefore, for the analysis of water level elevation comparison before and after climate change, it is divided into two periods: the analysis of the years 1996-2005 and the analysis of the years 2006-2018 as shown in Figure 8 and Figure 9.

Based on the comparison of the water level in the reservoir before climate change (1996-2005) and after climate change (2006-2018), it can be concluded that during the period before climate change, the annual inflow volume entering the reservoir was stable, so the water level in the reservoir could also be stable throughout the year, and its fulfilment needs not to be worried about. However, in the period after climate change, the annual inflow volume entering the reservoir decreased, causing the water level in the reservoir to be unstable throughout the year. Prioritization needs to be made for the fulfilment of its needs [21]–[25].

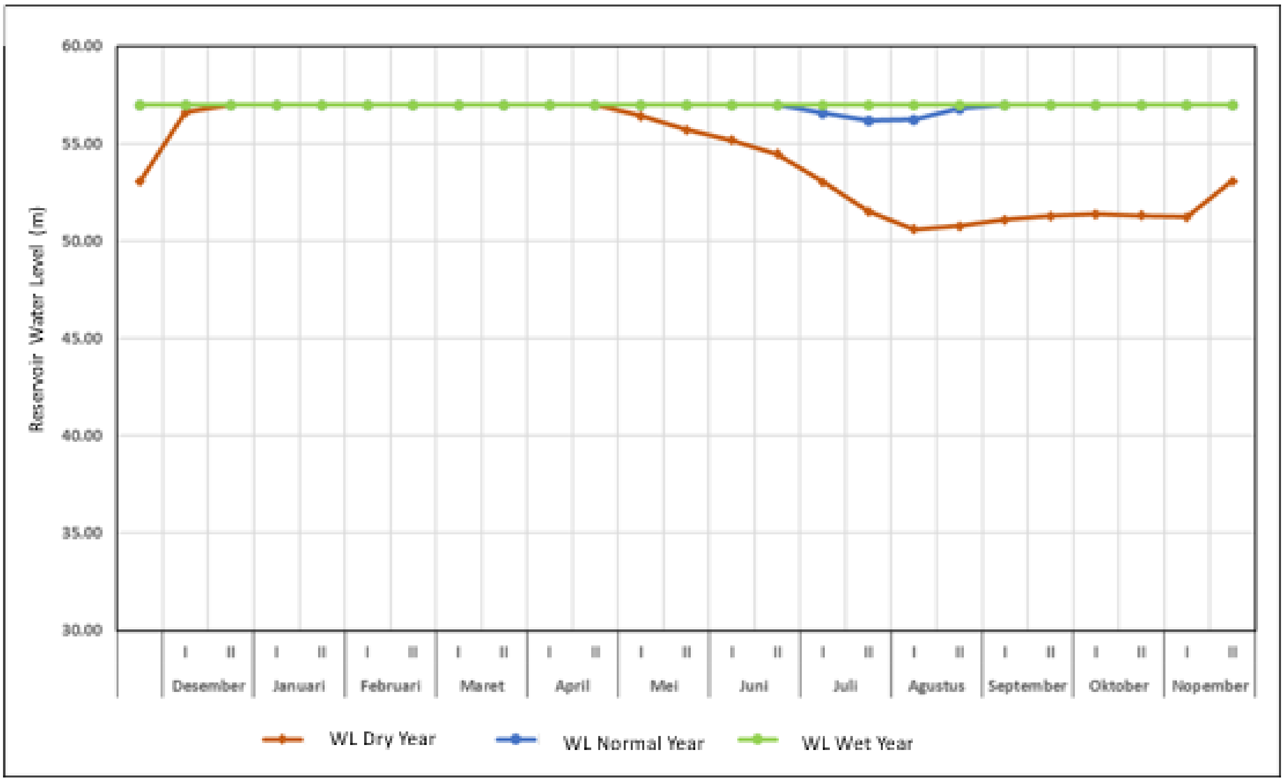

Figure 7. Rule Curve of Reservoir Operation in Dry, Normal, and Wet Years

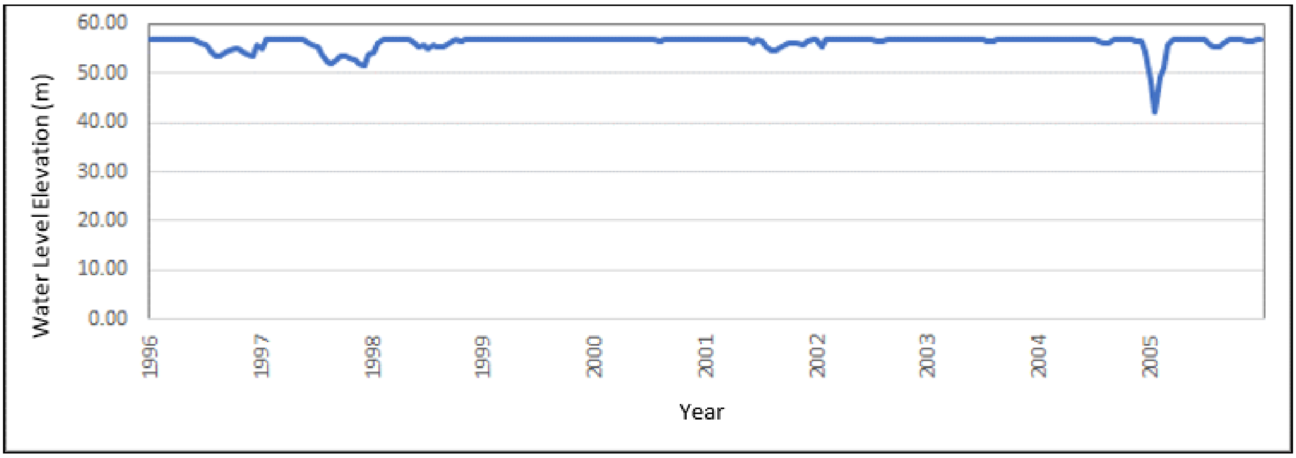

Figure 8. Graph of Water Level of Tiu Kulit Reservoir for the Period 1996-2005 During the Early Planting Season

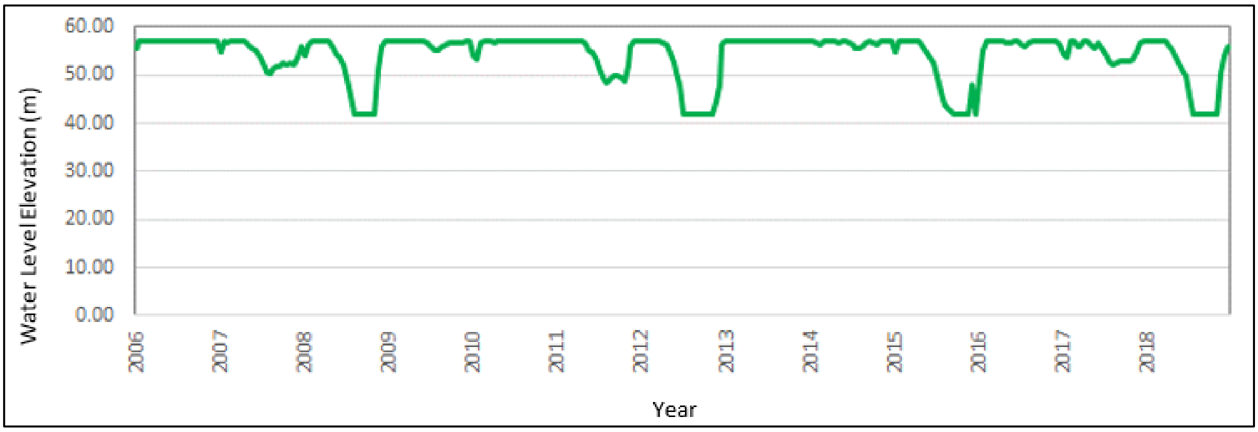

Figure 9. Graph of Water Level of Tiu Kulit Reservoir for the Period 2006-2018 During the Early Planting Season

4. Conclusion

This study determine the availability of water as an inflow for the Tiu Kulit Reservoir, the discharge of water demand as an outflow for Tiu Kulit Reservoir, and simulate Tiu Skin Reservoir in existing conditions, normal year, wet year, and dry year in order to get the operational pattern of the reservoir. The results of the reservoir storage simulation for dry, normal, and wet years are as follows:

a. During the dry-year simulation period, the lowest initial elevation was +53.07 m, which occurred at the end of 2011/2012, with the smallest annual inflow volume. At a water surface elevation of +53.07 m, various inflow rates for the dry year period were evaluated against the total water demand, including to determine any significant changes. Therefore, from a series of inflow volumes, the calculation was made with a 95% probability inflow discharge volume (P 95%) of 38.11 million m3. Thus, in the dry year period, water discharge for raw water, irrigation, and livestock drinking water needs could still be done fully (100%) up to a maximum of 1.20 m^3/s.
b. By analyzing the water surface elevation using a series of inflow rates against the total water demand during the normal year period, a reservoir water surface elevation simulation was carried out to obtain an equilibrium condition. The results of the simulation showed that with the lowest inflow rate of the normal year period, which was 52.74 million m3 (2015/2016), the effective reservoir storage volume did not experience a deficit for all 15-day periods in all months. Thus, for the overall normal year inflow rate, the water demand for raw water, irrigation, and livestock drinking water could be met 100% up to a maximum of 1.20 m^3/s.
c. Based on the series of inflow rates for the wet year condition, a reservoir water surface elevation analysis was conducted to obtain an equilibrium condition where the reservoir water surface elevation was at the NWL for almost all periods throughout the year. For the wet year, the maximum outflow rate was planned to meet the maximum total water demand for raw water, irrigation, and livestock drinking water needs at 1.20 m^3/s. For all wet-year inflow rates, starting the operation in a wet year would result in an increase in elevation above the spillway threshold, and spill out would occur.

The operational patterns for the Tiu Kulit reservoir are as follows:

a. Dry Year Operation Pattern. During a dry year, the water surface elevation is limited to an elevation of +53.07 m. If the reservoir water surface elevation is within this range, the maximum outflow rate that can be released is 1.20 m3/s. The outflow rate limit is maintained until the maximum water surface elevation of +57.00 m is reached, which is the normal water surface elevation limit for the beginning of the operation.
b. Normal Year Operation Pattern. The initial water surface elevation for normal year operation is +57.00 m, and the maximum outflow rate that can be released to meet the demand for raw water, irrigation, and livestock drinking water needs is 1.20 m3/s.
c. Wet Year Operation Pattern. Wet year operation is carried out at the NWL +57.00 m water surface elevation. However, it should be noted that all inflow rates for normal years also result in an elevation at the end of the period of +57.00 m NWL. The ideal condition for wet year operation is at an elevation of +57.00 m, where the maximum outflow rate of 1.20 m3/s can be released according to the demand. A balanced condition can occur for all wet year inflow rates, where the minimum water surface elevation in the following year is the same or higher than the previous year.

Based on the conclusions of this study, the following recommendations can be made:

a. Continuous observation and recording of reservoir inflow and outflow rates is necessary.
b. Installation of rain gauge stations within the Tiu Kulit reservoir catchment area is important to be used as data in the hydrological analysis.
c. Water supply needs can be increased based on population and livestock growth.
d. Optimization for the second planting season can be increased up to an intensity of 100% with a composition of 40% rice and 60% other crops
e. Periodic evaluation of the operational patterns is necessary every five years, given the climate changes that have occurred since 2006.

Author Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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