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Climate Change Impact on Water Availability and Water Balance on Sampit Cachtment, Central Kalimantan

(Pengaruh Perubahan Iklim Terhadap Ketersediaan Air dan Neraca Air DAS Sampit, Kalimantan Tengah)

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ABSTRACT

Sampit River is part of the Mentaya catchment area, located in the East Kotawaringin Regency, Central Kalimantan, Indonesia. Sampit River is generally used as a water supply for domestic, industrial, and livestock needs. The Mentaya River water balance shows that for the year 2030 projection, the Sampit River is expected to experience a deficit, specifically during the first period of the month of October. This research was conducted using the SSP 1 2.6 climate change scenario. In this scenario, it is estimated that rainfall will change from +2.282 to +1.020% and increase in temperature ranging from 0.441-0.793 ^{o}C within the period 2021-2030 to 2041-2050. The calculation of 90% dependable flow shows climate change impacts the period of the year 2030 to 2050 when compared to the existing dependable flow. Likewise, the 95% dependable flow for river maintenance, also increases. The research concludes that the water balance endures climate change impact and the calculated deficit remains the same for the first period of the month of October. The results of the water balance show that until 2050 climate change had not impeded negative effects but cautionary efforts must be taken as there an increasing deficits for the years 2040 and 2050.

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1. INTRODUCTION

Climate changes caused, directly or indirectly, by human activities that cause changes in the composition of the atmosphere globally and changes in natural climate variability observed over comparable periods are the definition of climate change.[1]. The impact of climate change, triggered by rising temperatures, results in shifts in rainfall patterns, and changes in the frequency of floods or droughts that adversely affect the agriculture, energy, transportation, and social sectors, which depend on water resources. In Indonesia, there has been an increase in average annual temperatures of around 0.3^0C, a decrease in rainfall by 2%-3%, changes in rainfall patterns, and changes in the rainy season where the rainy season increases in southern Indonesia and decreases in the north [2].

Sampit Sub catchment is one of the subs catchments in the Mentaya catchment area in Mentaya Katingan Watershed. Sampit Sub catchment is located in North Mentaya Hilir District, East Kotawaringin Regency. The Sampit River supplies water to PDAM Kotawaringin Timur (the regional water utility) and the SPAM Intake Unit of IKK Bagendang at a rate of 124 liters per second.[3]. PT. Globalindo Alam Perkasa and PT. Sapta Karya Damai rely on the Sampit River for their industrial water needs, amounting to 15.15 liters per second. Livestock in the area also depend on the river for water. PDAM Kotawaringin Timur water and SPAM intake Unit IKK Bagendang are planned to be able to meet the water needs of residents of North Mentaya Hilir District by 2050. Based on the calculation of the results of “Penyusunan Neraca Air Sungai Mentaya tahun 2023”, in 2030, the Sampit sub-catchment experienced a deficit of -0.009 m^3/s during the October 1 period [3].

Climate change, driven by increased greenhouse gas concentrations, profoundly affects hydrological processes and patterns worldwide. It is a global phenomenon, experiencing an increase due to human activities such as the use of fossil fuels and changes in land use.[4] The increasing population growth will heighten vulnerability to climate change. For every 1% increase in population, there will be a corresponding 1% increase in carbon emissions[5]. Hulme and Sheard (1999) showed that climate change has occurred in Indonesia, characterized by an increase in temperature of approximately 0.3°C and a decrease in annual rainfall of about 2–3%.[6] This phenomenon is further exacerbated by climate change, which is driven by increased greenhouse gas concentrations and profoundly affects hydrological processes and patterns worldwide.

In this context, the Sampit Sub-catchment, situated within the Mentaya Katingan Watershed in Indonesia, serves as a critical case study. The Sampit Sub-catchment plays a pivotal role in water supply for various purposes, including domestic use, industry, and livestock needs. However, climate change poses challenges to water availability, impacting both human communities and ecosystems. There needs to be research on the effect of climate change on water availability and water balance in the Sampit sub-catchment

Existing studies have highlighted trends in precipitation and evaporation, considering annual means, seasonal variations, and extreme events. However, few have comprehensively examined the combined changes in both annual mean and seasonal variation of these variables. Global climate classifications, which form the basis for water availability studies, often overlook seasonal variation characteristics from a non-parametric standpoint. Our research aims to assess the impact of climate change on hydrology within the Sampit Sub-catchment.

Climate change projections are based on Indonesia's climate projections which are CIMP phase 6 global climate compilation models.[7] The CIMP phase 6 (CMIP6) is a global climate model intercomparison project coordinated by the Program For Climate Model Diagnosis and Intercomparison (PCMDI) on behalf of the World Climate Research Program (WCRP). CMIP6 provides input for the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6). The scenario used is the SSP1 2.6 scenario. The SSP1-2.6 scenario ensures that global warming remains below 2°C relative to the 1850-1900 median period, with implied near-zero net emissions in the second half of this century. This scenario emphasizes the importance of reducing greenhouse gas emissions and achieving a balance between human activities and environmental impacts. Through collective efforts, we can sustain our planet for future generations The study was conducted by comparing the water balance in 2030, 2040, and 2050 in existing conditions and climate change scenario SSP 1 2.6. From the results of this study, it is expected to know the impact of climate change that occurs on the water balance in the Sampit Sub catchment.

1.1. Water Availability Analysis

Calculation of water availability using rain data which is then generated into discharge data with the FJ Mock method [8]. The Mock method principle states that some of the rain that falls on a catchment area will become direct runoff, while some will be lost due to evapotranspiration, and a portion will infiltrate into the soil [9]. The F. J. Mock Method is commonly chosen for simulating water balance due to its practicality, historical significance, and reliance on readily available data, making it suitable for assessing water availability and informing resource management strategies. FJ. The mock method is a monthly water balance simulation model for a drainage area, obtained from rain, evapotranspiration, soil, and groundwater storage[10]. Calculation of evapotranspiration using the Penman method, the climate data needed are temperature data (^{o}C), relative humidity (%), sunshine (%), and wind speed (mile/day) [11]. Parameters used in FJ Mock calculations are catchment area, infiltration coefficient, groundwater recession factor, soil moisture capacity, and evaporation potential [12]. The general equation for the F. J. Mock Method in water balance modeling is [13]:

[WS_i = (P_i - E_i) - SS_i]

Where: (WS_i) represents the water storage change (discharge) for a specific period.
(P_i) denotes the total precipitation during that period.
(E_i) represents the total evaporation during the same period.
(SS_i) corresponds to the surface runoff or subsurface flow during that period

Water availability is calculated using the dependable flow, which is the minimum discharge of the river that is affected by a certain probability value[14]. The calculation of dependable flow using the discharge duration curve can use the Weibull probability formula : [15]

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

P ($X \geq x$): the probability of occurrence of variable X equal to or greater than x, m^3/s
m: Data Ranking
n: amount of data
X: discharge data series
x: dependable flow if the probability is by its designation, for example, P ($X \geq 90\%$) = 0.90

For the use of raw water and industry, a dependable flow of 90% is used [16]. The use of a 90% dependable flow ensures a reliable water supply for raw water and industrial purposes. This level of dependability minimizes the risk of shortages during critical periods, making it suitable for sustaining operations and meeting daily requirements. Water availability analysis is calculated under existing conditions and climate change impact, with SSP1 scenario 2.6. The parameter that is considered in climate change is the increase in temperature (^oC) and change in rain (%) [7].

1.2. Water Demand Analysis

Water demand analysis, including PDAM water needs, and industrial and livestock water, based on research results in the final report on the Mentaya River Water Balance [3]. Livestock water demand is determined by the size of the livestock[17]. A comprehensive view of this can be found in Table 1.

Table 1 Livestock Water Demand by Type

Types of cattle	Water Requirement (l/livestock/day)
Cow, Horse, Buffalo	40
Pig	6
Giat, Sheep	5
Poultry	0.6

In general, water needs for livestock can be estimated by multiplying the number of livestock by the level of water demand based on the following equation:[18]:

$$Q_e = \left(q_{(1)} x P_{(1)} + q_{(2)} x P_{(2)} + q_{(3)} x P_{(3)}\right)\% \quad (2)$$

Q_e = Water demand for Livestock (l/day)
$q_{(1)}$ = Water demand for Cows, Buffaloes, and Horses (l/head/day)
$q_{(2)}$ = Water demand for Goats and Sheep (l/head/day)
$q_{(3)}$ = Water demand for Poultry (l/head/day)
$P_{(1)}$ = number of cows, buffaloes, and horses (heads)
$P_{(2)}$ = number of goats and sheep (heads)
$P_{(3)}$ = number of poultry (heads)

Maintenance flows are based on government regulation No. 38 of 2011 concerning Rivers and Law No. 17 of 2019 concerning Water Resources The explanation of Article 8 Paragraph 4 states that the priority of the people's right to water [14].

2. RESEARCH METHODS

Water balance is a comparison between the water availability and water demand in a place in a certain period, so that it can find out the amount of water there is a surplus deficit[19]. This research involves comparing the water balance calculations under existing conditions and those resulting from climate change using the SSP1 2.6 scenarios. Water Balance Calculations are calculated for existing conditions and the climate change impact in 2030, 2040, and 2050. The research flowchart can be seen in Figure 1

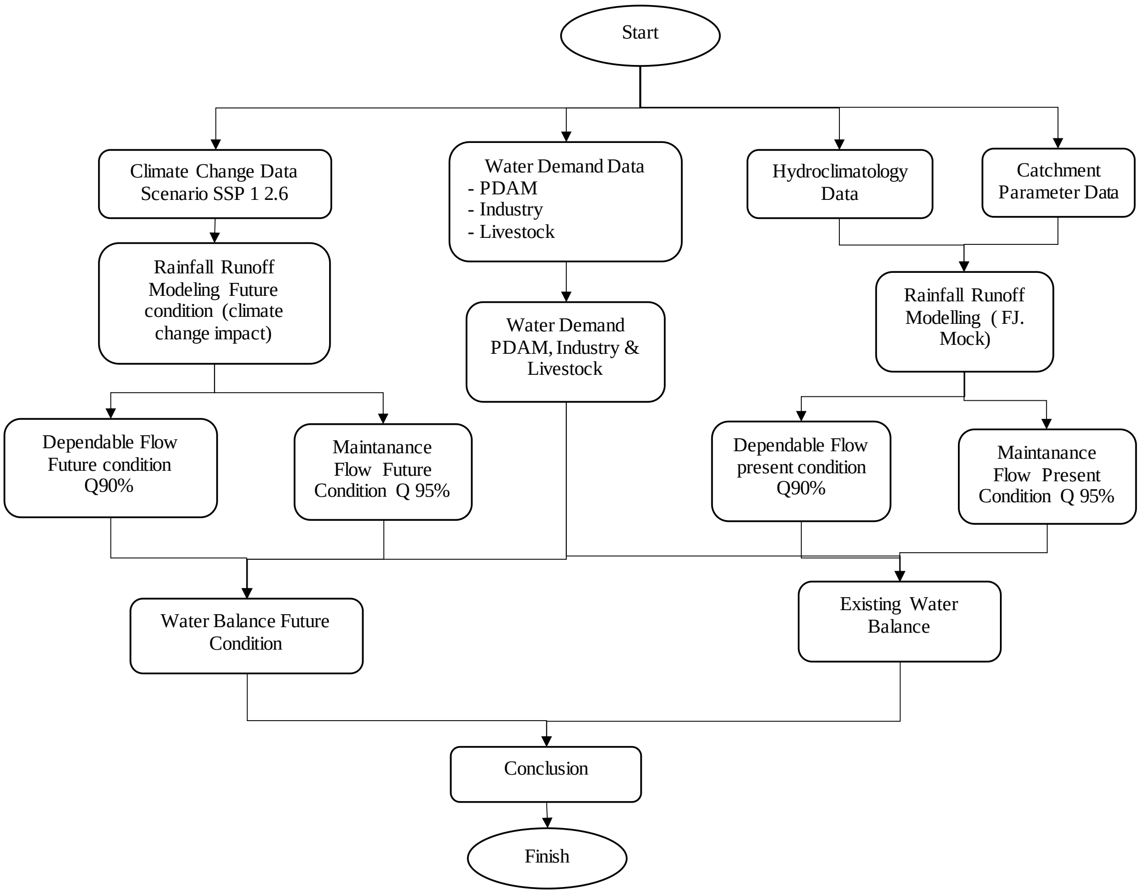

Figure 1 Water Balance Calculation Flow Chart

3. RESULTS AND DISCUSSION

This research aims to investigate the impact of climate change on water availability. The study is conducted in the Sub DAS Mentaya area, which has not been previously studied in terms of the effects of climate change on water availability. Previous research in the Sub DAS Mentaya has included an analysis of current water availability, water demand, and the water balance, including the largest deficit observed.

The data used in the analysis of water availability in the Sampit sub-catchment is rain and climate data from the Sampit Climate Post in 2003-2022. The changes in rainfall and temperature due to climate change can be seen in Table 3. FJ Mock parameters used in this calculation :[3]

Table 2 FJ. Mock Parameter

Location	Sampit Sub Catchment
Reflection Coefficient (r)	0.20
k (coefficient of evaporative surface roughness	1.00
Exposed Surface (m;%)	0.30
SMC	150.00
Infiltration Coefficient (if)	0.40
K (monthly flow recession constant)	0.45
PF (Percentage Factor)	10%
Catchment Area (km^2)	946.50
Land Use	Plantation

Table 3. Rainfall Changes & Temperature Rise Due to Climate Change

Month	Rainfall Change (%)			Temperature Increase (^{o}C)		
	2021-2030	2031-2040	2041-2050	2021-2030	2031-2040	2041-2050
Jan	2.460	2.550	3.360	0.430	0.630	0.670
Feb	1.010	3.170	3.280	0.470	0.630	0.720
Sea	2.200	0.580	0.740	0.420	0.630	0.790
Apr	2.790	3.830	3.700	0.460	0.670	0.790
May	2.320	3.330	3.860	0.380	0.600	0.750
Jun	1.770	0.440	0.230	0.420	0.640	0.820
Jul	5.490	0.340	-0.350	0.400	0.570	0.750
Aug	3.210	2.380	-0.660	0.490	0.570	0.850
Sep	3.310	0.740	-3.840	0.510	0.680	0.830
Oct	-0.670	-1.490	-2.580	0.460	0.670	0.870
Nov	0.990	1.430	0.810	0.420	0.680	0.900
Dec	2.500	1.540	3.690	0.430	0.540	0.770
Average	**2.282**	**1.570**	**1.020**	**0.441**	**0.626**	**0.793**

The climate change scenario SSP1-2.6 for the Sub DAS Sampit predicts changes from 2021 to 2050. On average, there is an increase in rainfall ranging from 2.282% to 1.020%, and a temperature rise between 0.441°C and 0.793°C. These findings indicate that both rainfall and temperature in the Sub DAS Sampit tend to increase during this period. As a result, the average calculations using the F. J. Mock method, considering climate change, also indicate an increase. This suggests that the impact of climate change can affect water availability within the system. Calculation discharge using the Mock Method was calculated for 20 20-year period, and with a dependable flow assumption of 90% reliability. Using the data on rain changes and temperature increases above, recalculations were carried out using the FJ Mock method and calculated the dependable flow Q90%. The results of the calculation of the dependable flow of the Sampit River are as follows :

Table* 4. *Dependable flow with a 90% reliability* and *based on climate change impact for the Sampit River

Month	Period	Dependable Flow 90% (m^3/s)	Dependable Flow based on climate change impact Q90% (m^3/s)		
			2030	2040	2050
January	I	26.082	26.833	27.31	28.351
	II	20.359	20.907	21.317	22.104

Month	**Period**	**Dependable Flow 90% (m^3/s)**	**Dependable Flow based on climate change impact Q90% (m^3/s)**		
			2030	**2040**	**2050**
February	I	15.321	15.746	16.189	16.839
	II	30.255	30.595	31.991	33.31
March	I	33.372	33.818	34.879	36.058
	II	43.773	44.809	45.028	45.027
April	I	34.491	35.689	37.142	37.748
	II	35.583	36.872	38.265	39.43
May	I	34.787	35.85	37.326	38.679
	II	23.817	24.526	25.488	26.52
June	I	11.797	12.144	12.572	12.999
	II	7.425	7.62	7.834	8.053
July	I	5.655	5.836	5.975	6.028
	II	2.150	2.245	2.286	2.316
August	I	1.121	1.155	1.185	1.195
	II	2.276	2.367	2.394	2.368
September	I	0.571	0.584	0.589	0.586
	II	0.301	0.313	0.313	0.303
October	I	0.182	0.188	0.189	0.187
	II	1.178	1.183	1.165	1.481
November	I	24.968	24.949	24.695	23.401
	II	25.856	25.939	25.927	24.972
December	I	29.862	30.125	30.364	30.277
	II	24.844	25.655	25.908	26.833
Average		**18.168**	**18.581**	**19.014**	**19.378**

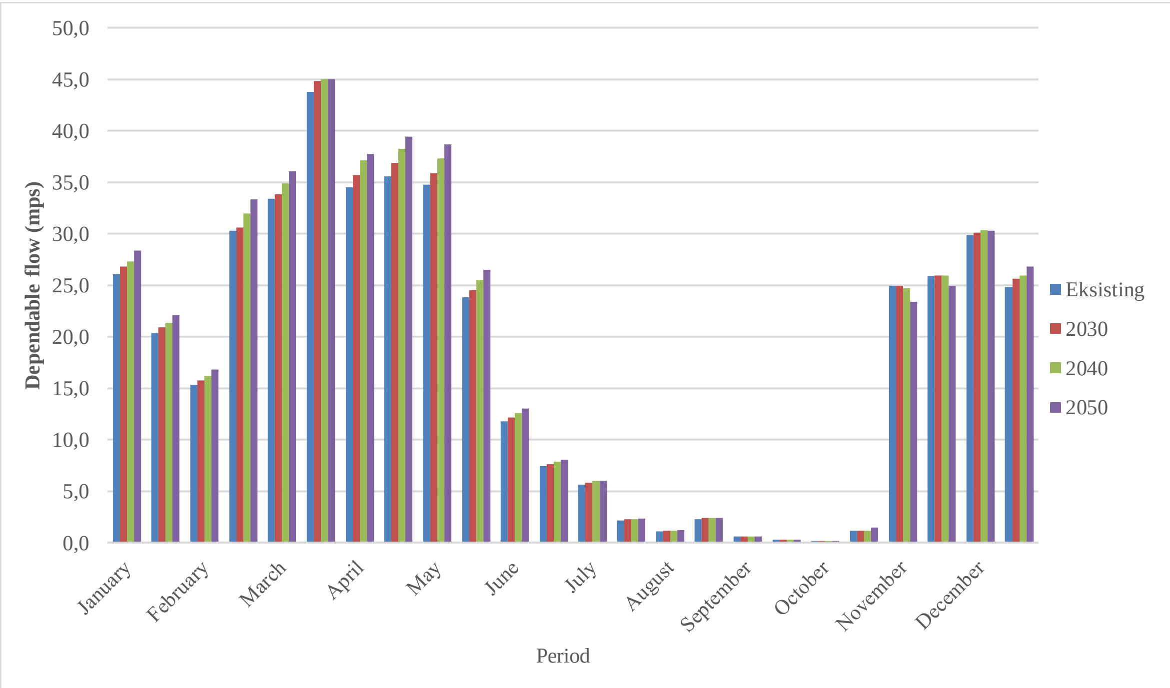

Figure 2 Dependable Flow of Various Scenarios

From the picture above, the results of the calculation of dependable flow based on climate change scenario SSP1 2.6 tend to increase from 2030 to 2050, especially in large discharges.

Water demand in the Sampit Sub catchment, in the form of PDAM, industrial, and livestock. PDAM water requirement to fulfill IPA at Kotawaringin Timur PDAM is 100 lps and IKK Bagendang Unit SPAM Intake is 24 lps.

Livestock in the Sampit Sub catchment are beef cattle, buffaloes, goats, sheep, pigs, laying hens, free-range chickens, and ducks [20]. Livestock water demand is calculated for 2030, 2040 and 2050. The results of calculating water demand as follows

Table 5 Water Demand

Water Demand	Water demand (lps)		
	2030	2040	2050
Industrial Intake Point	**0.0152**	**0.0152**	**0.0152**
- PT. Globalindo Alam Perkasa	0.0013	0.0013	0.0013
- PT. Sapta Karya Damai	0.0139	0.0139	0.0139
Livestock Water Demand	**0.0012**	**0.0012**	**0.0012**

Water requirements for river maintenance are taken from the smallest value of the maintenance flow Q95%.

Table 6 Maintenance Flow

Scenario	Maintenance Flow Q95% (m^3/s)
Existing Conditions	0.051
SSP1 2.6 - Year 2030	0.053
SSP1 2.6 - Year 2040	0.054
SSP1 2.6 - Year 2050	0.055

Water balance calculations are carried out for existing conditions and climate change impact with SSP1 2.6 scenarios in projections for 2030, 2040, and 2050.

Table 7. Water Balance Results Recapitulation

Month	Period	Existing (m^3/s)			Scenario SSP 1 2.6 (m^3/s)		
		2030	2040	2050	**2030**	**2040**	**2050**
January	I	25.890	25.890	25.890	26.640	27.116	28.156
	II	20.167	20.167	20.167	20.714	21.122	21.909
February	I	15.129	15.129	15.129	15.553	15.995	16.644
	II	30.064	30.064	30.064	30.402	31.796	33.115
March	I	33.181	33.181	33.181	33.625	34.684	35.863
	II	43.581	43.581	43.581	44.616	44.833	44.832
April	I	34.300	34.300	34.300	35.495	36.948	37.553
	II	35.391	35.391	35.391	36.679	38.071	39.235
May	I	34.596	34.596	34.596	35.657	37.131	38.484
	II	23.625	23.625	23.625	24.333	25.294	26.325

Month	Period	Existing (m^3/s)			**Scenario SSP 1 2.6 (m^3/s)**		
		2030	2040	2050	**2030**	**2040**	**2050**
June	I	11.606	11.606	11.606	11.951	12.377	12.804
	II	7.233	7.233	7.233	7.427	7.640	7.858
July	I	5.464	5.464	5.464	5.643	5.781	5.833
	II	1.958	1.958	1.958	2.051	2.091	2.121
August	I	0.930	0.930	0.930	0.962	0.990	1.000
	II	2.084	2.084	2.084	2.174	2.200	2.173
September	I	0.379	0.379	0.379	0.391	0.395	0.391
	II	0.109	0.109	0.109	0.119	0.119	0.108
October	**I**	-0.009	-0.009	-0.009	**-0.005**	**-0.006**	**-0.008**
	II	0.986	0.986	0.986	0.990	0.971	1.286
November	I	24.776	24.776	24.776	24.756	24.500	23.206
	II	25.664	25.664	25.664	25.746	25.732	24.777
December	I	29.671	29.671	29.671	29.932	30.169	30.082
	II	24.653	24.653	24.653	25.462	25.713	26.638
Deficit		-0.009	-0.009	-0.009	**-0.005**	**-0.006**	**-0.008**

The results of the calculation of the water balance obtained for existing conditions from 2030, 2040, and 2050 the results of the water balance deficit are relatively the same, namely -0.009 m^3/s, while by taking into account climate change in the SSP1 2.6 scenario in 2030 the visit decreases to -0.005 m^3/s, but in 2040 and 2050 the visit is getting bigger so that it is close to the existing condition deficit. The results of this water balance calculation align with the water availability calculations. In 2030, there will be an increase in rainfall, but this increase will diminish further by 2050. Meanwhile, the temperature consistently rises, especially by 2050. Although climate change may not have a significant impact until 2050, it is essential to remain vigilant about the conditions beyond that year.

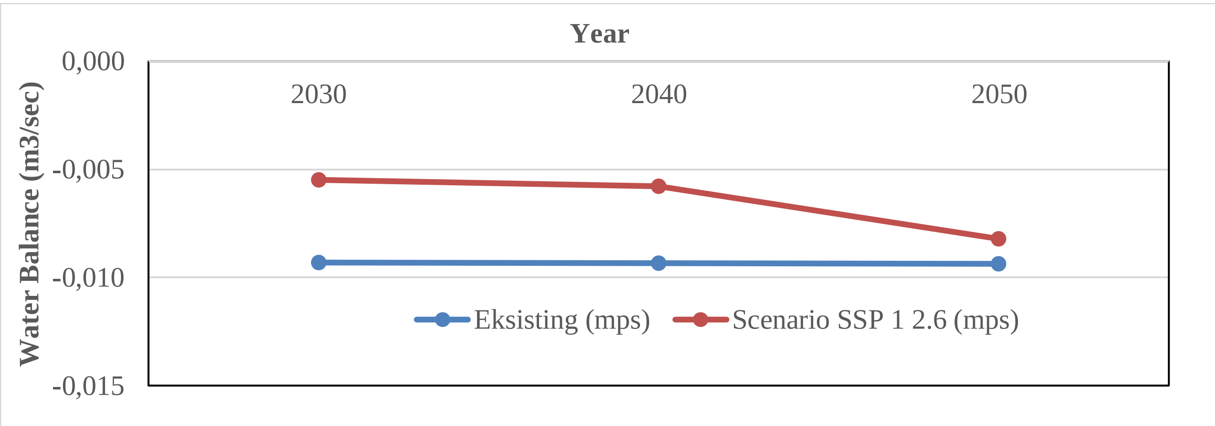

Figure 3 Deficit Value of Each Water Balance Scenario

4. CONCLUSION

The conclusion drawn from this research is that the existing water balance in the Sampit Sub-catchment experienced a deficit during the October 1 period in 2030, amounting to approximately -0.009 m^3/s. When considering the climate change scenario SSP1-2.6, there is an increase in rainfall by 2,282% in 2030, which subsequently decreases to 1,020% in 2050. Additionally, there is a temperature rise of 0.793°C in 2050. As a result of F. J. Mock's calculations with climate change, the average dependable flow (Q90%) increases from 2030 to 2050. Similarly, the maintenance flow (Q95%) also increases.

The water balance results indicate that climate change has not yet had a negative effect on water availability in the Sampit Sub-catchment until 2050. However, the increasing trend in deficit values beyond 2050 warrants continued vigilance. The trend of decreasing rainfall over time and the consistent temperature rise contribute to this observation. Therefore, conditions beyond 2050 need to be closely monitored due to the upward trend in deficit values.

The water balance calculations for existing conditions and climate change consistently show a deficit during the same period, namely October 1. The deficit value for the existing water balance is relatively consistent, approximately -0.005 m^3/s in 2030, which is smaller than the existing condition. This occurs because, due to climate change, the flow increases. However, there is a trend of increasing deficit, so by 2050, it will become approximately -0.008 m^3/s, approaching the existing water balance deficit.

The water balance results indicate that climate change has not yet had a negative effect on water availability in the Sampit Sub-catchment until 2050. This is because the trend of increasing rainfall diminishes over time, while the consistent rise in temperature continues from year to year. Therefore, conditions beyond 2050 need to be closely monitored due to the upward trend in deficit values

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