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Future Impacts of Climate Change on Streamflow and Sedimentation of Merawu Catchment, Indonesia

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Abstract. A study was conducted to assess the impact of climate change on the Merawu Sub-watershed in Indonesia, particularly in relation to the planned development of Indonesia Emas 2045. The sub-watershed is vulnerable to climate change due to the lack of proper soil and water conservation practices and the presence of a hydropower plant downstream. The study utilized the SWAT model to build a hydrological model and used data from GCM scenarios to analyze climate change and its impacts in 2035-2045. The results showed that there will be an increase in rainfall and a decrease in maximum and minimum temperatures in the sub-watershed during this period. The model indicated an increase in streamflow by 110.1% to 207.4% and sedimentation by 445.7% to 699%. The study highlights the need to address these changes to mitigate the risks of disasters and losses due to climate change in the Merawu Sub-watershed.

1 Introduction

Indonesia, a country experiencing rapid economic growth, has the potential to become one of the world's largest greenhouse gas (GHG) emitters by 2045 [1]. The ratification of the Paris Agreement through Undang-Undang Nomor 16 Tahun 2016 (Law of the Republic of Indonesia Number 6 of 2016) has elevated climate change to a national concern. The ratification signifies that the Government of Indonesia must limit the global temperature rise to below two °C by 2030. Furthermore, through Peraturan Presiden No. 59/2017 (Presidential Regulation No. 59/2017) on Sustainable Development Goals, the Government of Indonesia has agreed to ten goals related to future disaster management. One such goal is to strengthen adaptive capacity to climate change, extreme weather, drought, floods, and other disasters. These goals are outlined in Goal 2, Objective 2.4. This commitment presents a challenge in concurrence with the Visi Indonesia Emas 2045 (Golden Indonesia Vision 2045). Indonesia Emas 2045, which represents a milestone in the country's 100 years of independence, prioritizes economic development and growth with an average annual rate of between 5.1 and 5.7 percent [2]. Based on the presentation of the RPJPN Year 2025-2045 (National Long-Term Development Plan 2025-2045) by Bappenas (the National Development Planning Agency), it can be inferred that Indonesia will embark on a global expansionary phase in 2035 to increase economic growth to 7.6%. The pursuit of this economic vision may potentially lead to an increase in GHG emissions generated by existing development. This circumstance renders Indonesia more susceptible to the adverse effects of climate change, which could have a detrimental impact on the hydrological aspects of the watershed.

The Merawu Sub watershed is situated upstream of the Serayu Watershed, within the boundaries of Banjarnegara Regency. The Merawu Sub watershed encompasses an area of 23,260 hectares, with its highest point situated within the Dieng Plateau complex, subsequently flowing into the Mrica Reservoir [3]. Land use in the Merawu Sub Watershed has not been managed by conservation principles, resulting in suboptimal land potential and quality [4]. Most dryland agriculture in the Merawu sub-watershed is conducted on land with a high slope class. The combination of land use that does not prioritize water and soil conservation and considering topographic factors and rainfall has resulted in a high potential for landslides in the Merawu Sub Watershed [5]. The Merawu Sub watershed is characterized by a significant level of landslide vulnerability, necessitating close monitoring [6]. Additionally, the Merawu Sub watershed and its river is one of the inlets to the Merawu Reservoir, which PT Indonesia Power operates as a hydropower plant supplying electricity to the Central Java region. This renders the Merawu Sub watershed susceptible to the impacts of climate change.

The vulnerability of the Merawu Sub-watershed to climate change necessitates research into its impact on streamflow and sedimentation, which represent the most crucial component of the hydrological aspect. One approach to examining the impact of climate change in a watershed is to utilize SWAT modeling. SWAT has the advantages of a physical model, which include the ability to simulate hydrological conditions with parameters according to field conditions, to simulate long-term scenarios, and to run scenarios of changes in both climate change and land change in a hydrological model [6].

It is well documented that climate change affects the hydrological cycle, increasing the risk of hydro-meteorological disasters that can significantly impact the socio-economic life of the community. This study aims to determine the climate change condition in the Merawu Sub-watershed, build a hydrological SWAT model, and project the impact of climate change on streamflow and sedimentation in the Merawu Sub-watershed. By understanding the potential effects of climate change and its impacts on the Merawu Sub-watershed in the future, appropriate climate change mitigation measures can be formulated.

2 Methodology

The research was divided into three stages. The initial stage aims to analyze the projected climate change in the Merawu Sub watershed from 2035 to 2045 with two distinct scenarios. The next stage is to build a hydrological model with sensitive parameters in the Merawu Sub watershed between 2013 and 2022 as a baseline for comparison. Finally, the third stage aims to measure the impact of climate change on streamflow and sedimentation in the Merawu Sub watershed in each scenario.

2.1 Study Area

The research was conducted in the Merawu Sub-watershed, which is part of the Serayu watershed. In this study, Merawu Sub-watershed boundaries are derived from the results of automatic delineation using ArcSWAT with an area of 22,880 ha. Geographically, Merawu Sub watershed is located in Banjarnegara Regency, Central Java Province with coordinates -07°21'44.7089 "N, 109°41'19.6037" E and -07°10'16.3338 "N, 109°50'14.0222" W and covers several sub-districts namely Kalibening District, Karangkobar District, Banjarmangu District. Madukara District, Wanayasa District, Pejawaran District, and Batur District. The research location map is shown in **Figure 1.**

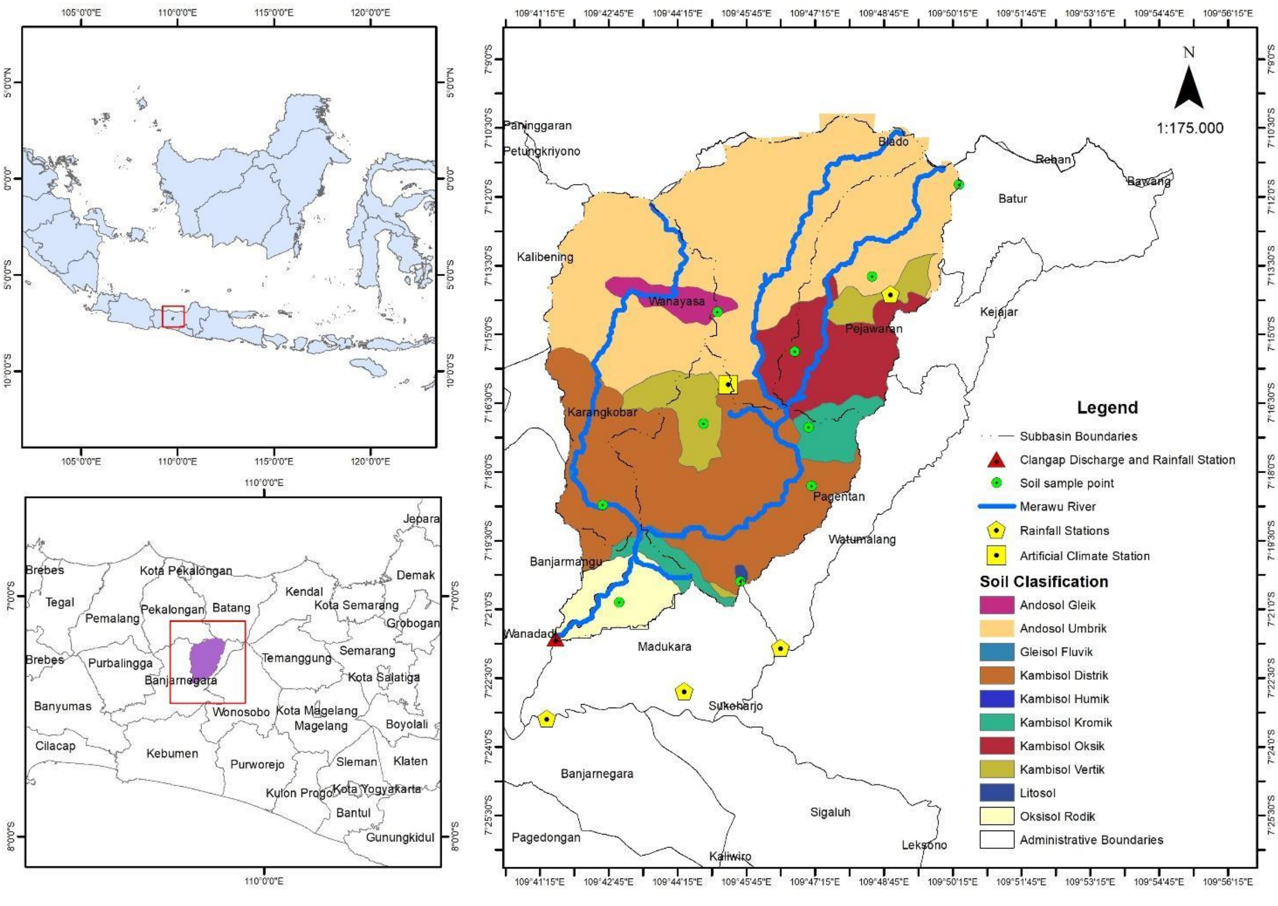


Fig. 1. Study Area Map

Merawu sub-watershed is located in the upper reaches of the Serayu watershed. Land cover in the Merawu Sub watershed is dominated by moor or field with an area of 10750 ha (47.15%), followed by plantation with an area of 4480 ha (19.65%), and then shrubs with an area of 3457 ha (15.116%). Then, settlements occupy an area of 1343 ha or 5.89%. The percentage of forest area in the Merawu Sub watershed is only 1.54% or 351 ha of the total area of the Sub watershed. There are nine soil types according to the semi-detailed soil classification in the Merawu Sub watershed, namely Andosol Gleic, Andosol Umbric, Gleisol Fluvic, District Cambisol, Cambisol Humic, Cambisol Chromic, Cambisol Oxic, Cambisol Vertic, Litosol, and Oxisol Rodic. The distribution of soil type classifications is shown in **Figure 1**. The Merawu Sub watershed is dominated by moderately steep and very steep areas with slopes of 15-25% and 25-40%.

2.2 Data Availability

This research uses two types of data: primary and secondary. Primary data used in this study are disturbed soil samples obtained from field activities. Determination of soil sample points using purposive sampling, which is then distributed randomly. The soil samples taken were then analyzed to determine the structure, texture, C-organic, and organic matter content. The soil parameters are then processed using SPAW software with the pedotransfer function to build the SWAT model in the user soil database section. Secondary data in this research is divided into spatial and non-spatial data. The spatial data used is a semi-detailed soil type distribution map of the Serayu watershed sourced from BPDAS SOP, a 2023 land cover map from BPKH Region XI Yogyakarta, and DEM SRTM. Non-spatial data used in this study are daily rainfall data from rainfall stations in and around Merawu Sub-watershed from the Dinas PU Unit Hidrologi of Banjarnegara and daily streamflow observation data of Clangap Station from PUSDATARU Jawa Tengah. Evapotranspiration factor data was obtained through NASA's PowerLARC. Climate change data in this study was obtained from the Copernicus CDS website, which provides SEA-CORDEX data or GCM data that has been reduced to RCM on a regional scale in the Southeast Asia region. Two GCMs, namely MPI-M-MPI-ESM-MR RU-CORE-RegCM4-3 (Germany) and NOAA-GFDL-ESM2M - RU-CORE-RegCM4-3 (USA), were selected in this study.

2.3 Climate Change in Merawu Sub-watershed

Climate change data was obtained by extracting NETCDF format files downloaded from the Copernicus CDS website. NetCDF is a format for storing climatic data resulting from modeling from worldwide climatology research institutions. BMKG Indonesia (the Meteorology, Climatology, and Geophysics Agency) also uses the two models selected to project hydrometeorological disasters and their vulnerability in the future. SEA-CORDEX data has a resolution of 0.22 degrees × 0.22 degrees or equal to 22 km × 22 km. The variables used in this study are daily rainfall and daily maximum-minimum temperature at the centroid point of the Merawu Sub-watershed. The scenarios used in this study are RCP 4.5 and RCP 8.5 scenarios for 2035-2045. Furthermore, trend analysis was conducted using the Mann-Kendall test and Sen's Slope Estimator to determine whether there is climate change and the direction of change. The Mann-Kendall test is a statistical test to determine whether data changes are significant [7]. The Mann-Kendall test has been widely used to analyze hydrometeorological data trends [8].

2.4 Merawu Sub-watershed SWAT Hydrological Model

The baseline hydrological model in the Merawu Sub watershed was built using the Soil and Assessment Tool (SWAT). The SWAT model is a physical-based model that can simulate complex processes in a watershed with diverse spatial and temporal data [9]. The baseline period used in this study is 2013-2022, and the calibration period used is 2019-2020. Calibration and validation were carried out using the SUFI2 algorithm using SWAT-CUP.

The SWAT model was originally designed to model the hydrological cycle in watersheds with a temperate climate or four seasons during the year. Therefore, it is necessary to adjust the model to the tropics. Parameter adjustments were made based on research conducted by [10]. The adjustments are listed in **Table 1.**

Table 1. Adjusted parameters related to tropical sub-watershed.

Parameter	Before			After		
	Forest	Shrub	Agriculture	Forest	Shrub	Agriculture
LAI_INIT (-)	0	0	0	5	3	3
BIO_INIT (kg/ha)	0	0	0	1000	0	0
PHU_LT (-)	0	0	0	3500	3500	3500
GSI (mm/s)	2	5	7	7	5	7
CANMX (mm)	0	0	0	5	2	2

The first component adjusted in this study is the initial leaf area index (LAI_INIT) or leaf area in m^2 per unit area (m_2). The initial value of LAI_INIT in SWAT is 0. This indicates that at the beginning of the baseline period, the assumption is that vegetation is newly planted so that the leaf area factor in evapotranspiration cannot be considered in the early part of the period. Adjustments were made by changing the LAI_INIT value to not 0. This was done because in the baseline simulation, land cover in the Merawu Sub watershed was considered to be covered by vegetation. LAI values that have been adjusted to the conditions of tropical watersheds can affect the more representative evapotranspiration process. LAI is a parameter that is very influential in hydrological processes through the dynamics of vegetation components [11]. The calculation of the LAI value in SWAT is based on the average density of a land cover in an HRU [12]. The adjustment of the LAI value in the model used in this study refers to [10] by replacing the LAI_INIT value based on land cover.

The second component is the initial dry weight biomass (BIO_INIT in kg/ha). The biomass value in the initial SWAT model that has not been adjusted is also determined by assuming that the initial time in the baseline period is when vegetation has not grown so that the BIO_INIT value is 0. This condition is adjusted by filling the BIO_INIT value to the maximum value for each land cover in the HRU. The biomass value of a plant affects the plant's metabolism in utilizing water and light. This also affects the biomass value and the evapotranspiration value.

The third component is the potential heat unit (PHU_LT). This component is the amount of heat plants require to reach harvest or maturity. High PHU_LT values are included in the SWAT model to represent the conditions of tropical watersheds that receive sunlight throughout the year. Furthermore, the fourth component is GSI. GSI is the ability of stomata to continue transpiring under conditions of high sunlight and low humidity. The last component is CANMX, which is the maximum canopy capacity. High GSI and CANMAX represent tropical watershed conditions where there is no significant difference in sunlight in one year and the dominance of vegetation components that can store water in the canopy.

Calibration and validation in SWAT-CUP are conducted by selecting sensitive parameters for calibration. The selection of sensitive parameters in a watershed is based on either literature or sensitivity analysis. This research employs literature studies to determine the parameters to be calibrated. The selection of parameters identified those considered sensitive in tropical watersheds. The calibrated parameters are listed in **Table 2**.

Table 2. Calibrated parameters and their initial value

Parameter	Initial minimum value	Initial maximum value	Source
v__SHALLST.gw	0	1000	[13]
v__GW_DELAY.gw	0	200	[13]
v__GWHT.gw	0	25	[13]
v__CH_K2.rte	0.01	150	[13]
r__CN2.mgt	-1	1	[13]
r__ESCO.hru	-1	1	[13]
r__SLSUBBSN.hru	-1	1	[13]
r__SOL_AWC().sol	-1	1	[13]
r__SOL_BD().sol	-1	1	[13]
r__SOL_K().sol	-1	1	[13]
r__RCHRG_DP.gw	-20	5	-
v__EPCO.hru	0	1	[14]
r__SOL_ALB().sol	0	0.25	[15]
v__ALPHA_BF.gw	0	1	[15]
v__SURLAG.bsn	0	10	[16]

The accuracy of the streamflow simulation model produced bt SWAT was evaluated by the coefficient of determination (R^2) equation and the Nash-Sutcliffe Efficiency [17]. The R^2 value indicates the strength of the linear relationship between the observed and simulated values. The ENS value, on the other hand, indicates how well the observed value plots in comparison to the simulation [18]. The equation and model performance based on NSE and R^2 values are listed in formulas (1) and (2), respectively.

$$ENS = 1 - \left[\frac{\sum_{i=1}^{t}(QMi - QSi)^2}{\sum_{i=1}^{t}(QMi - \underline{QMi})^2}\right] \text{....(1)}$$

$$R^2 = \left[\frac{\sum_{i=1}^{t}\left(Qmi - \underline{Q}mi\right)(Qsi - \underline{Q}si)}{\sqrt{\sum_{i=1}^{t}\left(Qmi - \underline{Q}mi\right)^2}\ \sqrt{\sum_{i=1}^{t}(Qsi - \underline{Q}si)^2}}\right]^2 \text{....(2)}$$

Where the symbol stands as explained below

R^2 = Determinance Coefficient
E = Nash-Sutcliffe coefficient
QSi = Simulated streamflow
QMi = Observed streamflow
$\underline{Q}si$ = Average simulation streamflow
$\underline{QMi}$ = Average observed streamflow
n = Number of data

The resulting values of NSE and R^2 show the performance of the model used. The **Table 3** shows the model performance based on the NSE and R^2 values [19].

Table 3. Model performance based on NSE and R^2

NSE	R2	Model performance
$0.75 < NSE \leq 1.00$	$0.75 < R^2 \leq 1.00$	Very good
$0.60 < NSE \leq 0.75$	$0.60 < R^2 \leq 0.75$	Good
$0.36 < NSE \leq 0.60$	$0.50 < R^2 \leq 0.60$	Satisfying
$0.00 < NSE \leq 0.36$	$0.25 < R^2 \leq 0.50$	Less satisfactory
$NSE \leq 0.00$	$R^2 \leq 0.25$	Not qualified

2.5 Climate change impact on streamflow and sedimentation in Merawu Sub watershed

The impact of climate change is assessed through the re-execution of the SWAT model with a series of modifications. The first adjustment is to replace the parameter values of the simulation model with parameter values based on the calibration results. This is done so that the new model approaches the original conditions. The parameter adjustments are made using the Edit SWAT Input feature and changing the database values in the subbasin. Furthermore, the climate variable data is replaced with climate data corresponding to the scenario RCP4.5 and RCP8.5. This replacement is conducted by modifying the rainfall, maximum temperature, and minimum temperature variables within the climate data input section (pcp and tmp). Following this, the model is executed once more. The model output comprises streamflow and sedimentation, which are then subjected to analysis based on the specific climate change scenarios.

3 Result and Discussion

3.1 Climate change in Merawu Sub watershed

The phenomenon of climate change can be studied from two things, namely, the changing character of rainfall and temperature in a region [20]. Rainfall and temperature variability directly affect the water cycle process in an ecosystem [21]. Increased precipitation is one of the critical factors driving soil erosion [22]. The most common approach to determine how climate conditions will change in an area is to use the RCP scenario published by the IPCC. The RCP scenario is a product of collaboration between experts in climate change modeling, socioeconomics, land management, and carbon emission rates [23]. The scenarios used in this study are RCP4.5, or moderate climate change mitigation efforts, and RCP8.5, which is no climate change mitigation efforts or business as usual.

Climate change in the Merawu Sub watershed is illustrated by graphing daily rainfall and temperature distribution for ten years, starting from 2035-2045. Furthermore, trend analysis was conducted to determine the direction and significance of each variable. Mann-Kendall and Sen Slope Estimator tests were conducted on the average annual data in each scenario or mean annual from 2035-2045. The results of the Mann-Kendall Test and Sen Slope Estimator are listed in Table 4.

Table 4. Mann-Kendall and Sen’s slope result on Climate Variable.

Scenario (Mean-Annual)	**Mann-Kendall**		**Sen's slope**
	p-value	z	
Precipitation RCP4.5	0.5334	-0.6228	-7.249721
Precipitation RCP8.5	0.2129	1.2456	54.14186
Maximum temperature RCP4.5	0.6404	0.4671	0.02716859
Minimum temperature RCP4.5	0.5334	0.6228	0.03467287
Maximum temperature RCP8.5	0.06171	1.8684	0.176025
Minimum temperature RCP8.5	0.5334	0.6228	0.0346

Based on the results of the analysis, it is known that there are no climate component variables that experience significant changes in the scenario time span (2035-2045). This can be seen from the p-value of the variable, which is not less than 0.05. A p-value greater than 0.05 indicates that there is no statistically significant trend at the 95% confidence level. Positive z-values except for rainfall in the RCP45 scenario indicate an increasing but statistically insignificant climate trend direction. Meanwhile, positive Sen's slope values also indicate an increase, albeit not significant, in the data over time. No statistically significant climate change occurred in the scenario period (2035-2045). The change percentage of climate variables is shown in **Tables 5, 6, and 7.**

Table 5. Change percentage of mean-annual rainfall

Scenario	Mean-Annual Rainfall (mm)	Change Percentage (%)
Baseline	3186.06	-
RCP45	6761.34	112.22
RCP85	8640.35	171.19

Table 6. Change percentage of mean-annual maximum temperature

Scenario	Mean-Annual Maximum Temperature	Change Percentage (%)
Baseline	29.11	-
RCP45	21.84	-24.97
RCP85	22.87	-21.46

Table 7. Change percentage of mean-annual minimum temperature

Scenario	Mean-Annual Minimum Temperature	Change Percentage (%)
Baseline	23.70	-
RCP45	19.91	-15.98
RCP85	20.03	-15.51

Based on the calculations listed in **Tables 5, 6, and 7**, the change in rainfall in the RCP45 scenario is 112%, and for the RCP85 scenario, it is 171%. As for the maximum temperature, it is known that there is a decrease of 24.97% for the RCP45 scenario and a decrease of 21.46% for the RCP85 scenario. Furthermore, at minimum temperature, it is known that both scenarios have decreased by 15%. Then, daily rainfall distribution plots were made to analyze the distribution variability in each scenario. Climate variability causes fluctuations in rainfall and shifts in the timing of rainfall events so that rain cannot be predicted and tends to be erratic [24]. The plot is shown in **Figure 2** and **Figure 3**.

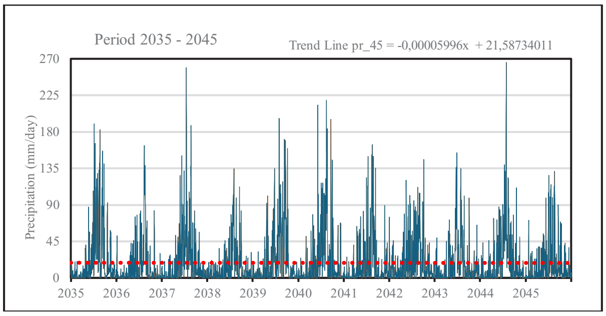


Fig.2. Daily rainfall plot from 2035 to 2045 based on RCP4.5 Scenarios.

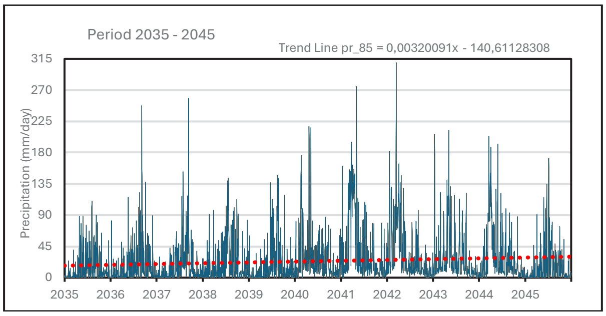


Fig.3. Daily rainfall plot from 2035 to 2045 based on RCP8.5 Scenarios.

Based on **Figure 2** and **Figure 3**, it is known that there are differences in the distribution of rainfall during the period. Rainfall in 2035 in the RCP8.5 scenario is higher than rainfall in 2035 in the RCP4.5 scenario. Based on the trend line, it is also known that rainfall in the RCP8.5 scenario has increased throughout the period, although the trend is thin. Meanwhile, rainfall in the RCP4.5 scenario does not show an increase from the trend line. This shows that the distribution of rainfall in the RCP45 scenario is more evenly distributed throughout the period than the distribution of rainfall, which tends to increase in the RCP8.5 scenario. This difference in rainfall distribution has implications for watershed management in the Merawu Sub watershed related to flood and landslide risk management. In addition, this difference can also affect community activities, especially agriculture and plantations.

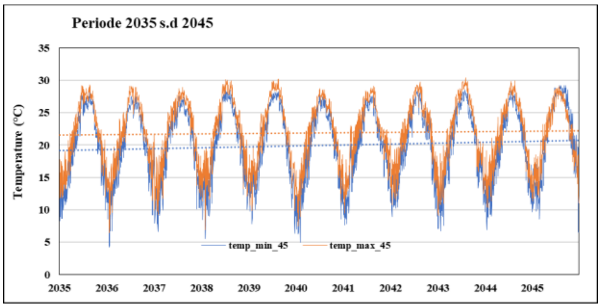


Fig.4. Daily temperature plot from 2035 to 2045 based on RCP4.5 Scenarios.

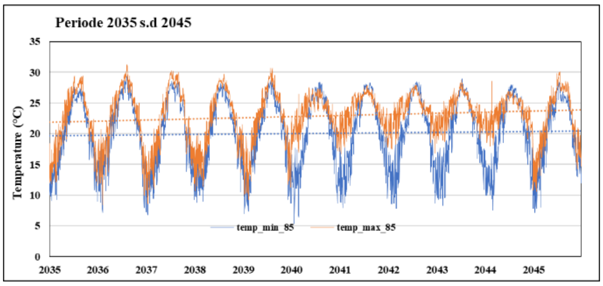


Fig.5. Daily temperature plot from 2035 to 2045 based on RCP8.5 Scenarios.

Based on the trend visualization image in **Figure 4 and Figure 5**, it is known that there is a difference in maximum temperature around 2040-2044, wherein the RCP8.5 scenario, the maximum temperature is higher than the RCP4.5 scenario. The difference between maximum and minimum temperatures in the RCP8.5 scenario in 2040-2044 is also greater than in the RCP4.5 scenario. The trend lines in each scenario show an increase, although not significant, during the period 2035-2045. Generally, there will be an increase in precipitation and temperature in each of the RCP4.5 and RCP8.5 scenarios [22].

3.2 Merawu Sub watershed SWAT hydrological model

After the SWAT simulation was done in the baseline period, the calibration and validation process was carried out to determine the range of sensitive parameters in the Merawu Sub-watershed. The calibrated parameters are then sorted based on their sensitivity using SWAT-CUP. **Table 8** shows the sensitivity of the parameters used in this study.

Table 8. Sensitivity analysis of calibrated parameter

Parameter Name	t-Stat	P-Value	fitted_value
9:R__SOL_BD(..).sol	6.52	0.00	-0.189078
8:R__SOL_AWC(..).sol	5.26	0.00	2.428410
10:R__SOL_K(..).sol	1.68	0.09	-0.588464
6:R__ESCO.hru	-1.28	0.20	0.750000
4:V__CH_K2.rte	-1.27	0.21	82.238228
5:R__CN2.mgt	1.14	0.25	-1.009033
13:R__SOL_ALB(..).sol	-1.10	0.27	0.001832
3:V__GWHT.gw	-1.07	0.29	12.105465

7:R__SLSUBBSN.hru	-0.97	0.33	1.971753
14:V__ALPHA_BF.gw	0.91	0.36	-0.188928
1:V__SHALLST.gw	-0.88	0.38	846.413879
12:V__EPCO.hru	-0.60	0.55	0.904682
11:R__RCHRG_DP.gw	0.26	0.80	-15.744514
15:V__SURLAG.bsn	-0.19	0.85	0.781921
2:V__GW_DELAY.gw	-0.02	0.99	30.692442

The first sensitive parameter based on *sensitivity analysis* is Sol_BD or *bulk density*. *Bulk density* affects infiltration capacity and soil water storage. The denser the soil or the higher the SOL_BD value, the less infiltration capacity and the more surface runoff. *Bulk density* is influenced by factors such as texture, structure, and soil organic matter content [25]. High organic matter can improve soil quality by triggering the activity of soil organisms that can improve soil porosity and aggregate stability [26]. This can cause *bulk density* to be low if a location has good organic matter conditions.

The next sensitive parameters are SOL_AWC and SOL_K. These two parameters also relate to the soil's infiltration process and water capacity. SOL_AWC is the available water capacity in each soil horizon. While SOL_K is the saturated hydraulic conductivity or permeability of the topsoil horizon. A high SOL_K value will increase the infiltration rate in the soil. The high SOL_K value then needs to be supported by the higher SOL_AWC value. A high SOL_AWC indicates that the capacity to store water in the soil will be greater, causing less water to become *surface runoff* and percolation [27].

Then, the fourth sensitive parameter is ESCO. ESCO is defined as the compensation factor for evaporation from the soil. ESCO directly affects the amount of water that can evaporate from the soil surface. The higher the ESCO value, the less water from the soil surface evaporates in the evapotranspiration process, leading to more *surface runoff* [21]. The parameter is sensitive because it is in accordance with the conditions of the Merawu Sub-watershed, which is a tropical area with a high level of evaporation. The study by [27] showed that SOL_AWC and ESCO also strongly influence the streamflow generated in watersheds with climates with higher temperatures and longer solar irradiation. Then, there are 11 other parameters with less sensitivity.

The model evaluation examines the three *objective function* values generated after the 11th iteration process. The three *objective functions* are R^2, NSE, and PBIAS. The model evaluation results are listed in **Table 9.**

Table 9. Objective functions of calibration and validation period

Period	Objective function		
	R2	NSE	PBIAS
Calibration (2019)	0.62	0.58	-6.7
Validation (2020)	0.56	0.51	3.8

The $R^{2,}$ or the coefficient of determination, shows how collinear the simulated data is with the observation data [21]. While NSE shows how suitable the flow curve is between the observation streamflow and the calibrated simulation data. Then, PBIAS shows the percentage of *slope* difference between the simulation debut and observation streamflow. If the R^2 and NSE values are closer to 1, then a model can be said to have good performance. Acceptable PBIAS values in hydrological models are in the range of -15% to 15% with positive results indicating underestimation and negative numbers indicating overestimation by the model [21].

Based on **Table 9.** The performance of the model run is in the range of good (R^2>0.6) and good (NSE>0.5). Iterations that are run to improve the performance of the next model cannot produce changes in the value of the *objective function*. Based on this, the best set of model parameters will be used as new parameters in the SWAT model**. Figure 6** shows the hydrograph from the simulation and calibration period

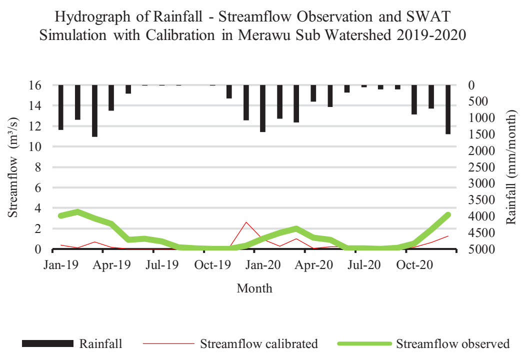


Fig.6. Hydrograph of Rainfall - Streamflow Observation and SWAT Simulation with Calibration in Merawu Sub Watershed 2019-2020

Subsequently, a map of sedimentation distribution in the Merawu sub-watershed was constructed. The objective was to identify the areas within the Merawu Sub-watershed that exhibited the highest levels of sedimentation. The process of creating the map entailed the accumulation of the average sediment per year during the baseline period in each sub-basin. This is calculated on a yearly basis for each sub-basin during the baseline period. The map is shown in **Figure 7**.

It should be underlined that in this study, calibration was only carried out using observed streamflow data. The absence of recorded sedimentation data meant that model calibration for sedimentation could not be performed.

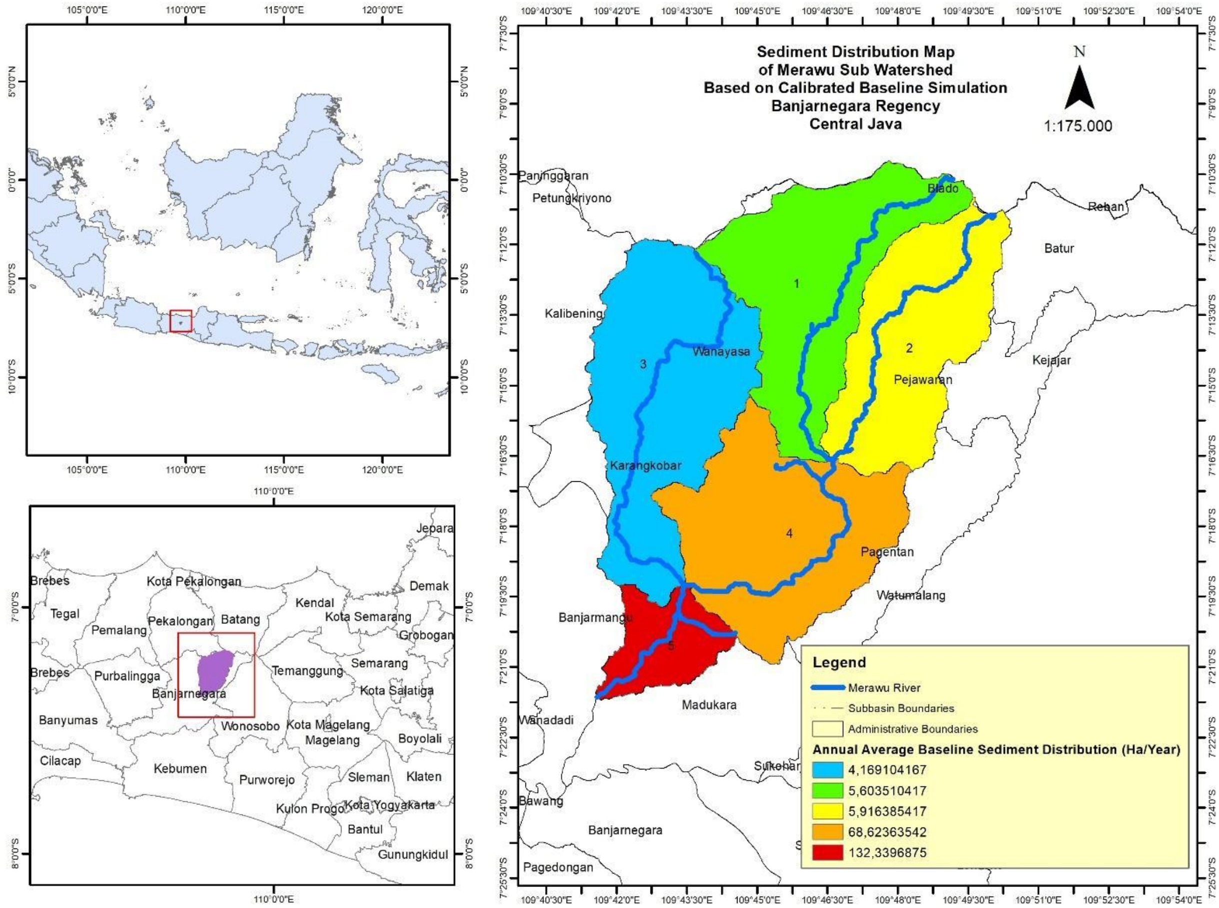


Fig.7. Sediment Distribution Map of Merawu

The sedimentation distribution map indicates that subbasin 3 has the lowest sediment levels, averaging 4.17 tons/ha/year. Subbasin 1 has the second lowest sediment levels, averaging 5.603 tons/ha/year. Subbasin 2 is the third-ranked subbasin, with a sediment yield of 5.91 tons per hectare per year. Subbasin 4 is in fourth position, with a sediment yield of 68.62 tons per hectare per year. Subsequently, subbasin 5 is identified as the subbasin with the highest sediment concentration, exhibiting a sediment load of 132.33 tons per hectare per year. As illustrated in the distribution map, sediment accumulation in the downstream region is significantly greater than that observed in the upstream region.

The sedimentation process occurs due to the transportation of sediment from higher elevations to downstream regions. This can result in the accumulation of sediments and subsequent siltation of reservoirs, rivers, and irrigation channels. The accumulation of sediments in downstream regions increases the quantity of sediment within the subbasin.

3.3 Climate change impact on streamflow and sedimentation in Merawu Sub-watershed

The impact of climate streamflow on streamflow and sedimentation in the Merawu Sub watershed was calculated using the calibrated SWAT model and input of temperature and precipitation generated through GCM data extraction. Due to data limitations, evapotranspiration is calculated using the Hargreaves equation. The Hargreaves equation only uses daily temperature and precipitation data to find the relationship of solar radiation values through regression equations, which will later be used to determine evapotranspiration values [28].

The scenario period is set with three years as warming up so that the baseline period and climate change scenario periods have the same number of years. After running the model again, visualization was done using hydrographs. Visualization is done to see how the pattern of streamflow and sedimentation during the scenario period. **Figure 8** shows a hydrograph of the projected streamflow and sedimentation in the Merawu Sub-watershed due to climate change.

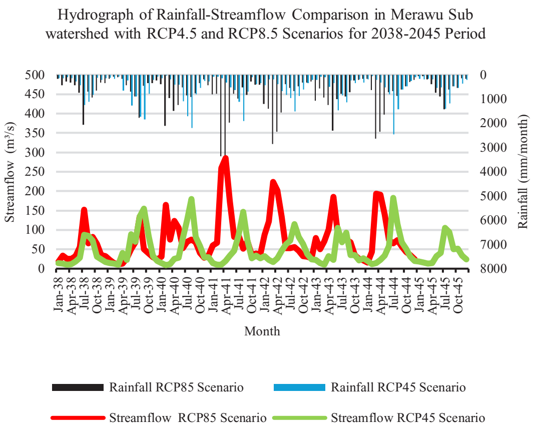
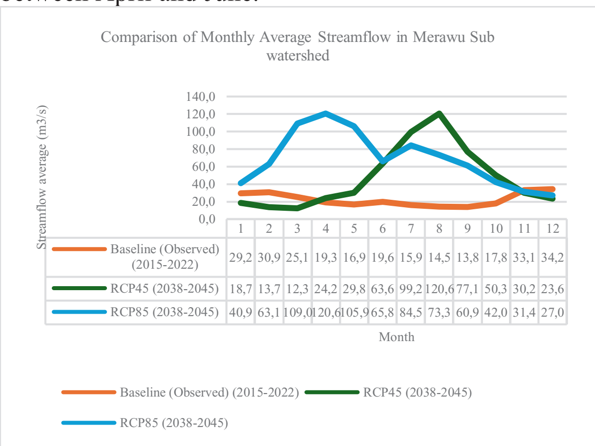


Fig.8. Hydrograph of Rainfall-Streamflow Comparison in Merawu Sub watershed with RCP4.5 and RCP8.5 Scenarios for 2038-2045 Period.

Figure 8 shows that the streamflow peak is consistent with the rainfall peak. This indicates a direct influence between rainfall and stream streamflow. There is a seasonal pattern per month that is recorded in the hydrograph. The RCP4.5 scenario shows an increase in streamflow throughout the period, which was recorded consistently in July. The graphics show a decrease in streamflow occurred starting from January and October. Large average streamflow above 100 m3/s shows the implications of possible flood events that can occur in the Merawu Sub-watershed. The RCP4.5 scenario shows the importance of future flood risk mitigation planning in the middle of the year. The RCP8.5 scenario shows that the peak streamflow and rainfall in the scenario are higher than with the RCP4.5 scenario. Streamflow peak and rainfall also occur earlier, namely between April and June.



	1	2	3	4	5	6	7	8	9	10	11	12
Baseline (Observed) (2015-2022)	29,2	30,9	25,1	19,3	16,9	19,6	15,9	14,5	13,8	17,8	33,1	34,2
RCP45 (2038-2045)	18,7	13,7	12,3	24,2	29,8	63,6	99,2	120,6	77,1	50,3	30,2	23,6
RCP85 (2038-2045)	40,9	63,1	109,0	120,6	105,9	65,8	84,5	73,3	60,9	42,0	31,4	27,0

Fig.9. Comparison of Monthly Average Streamflow in Merawu Sub-watershed

Figure 9 shows the monthly average trends in each scenario. The average observed streamflow shows that during the baseline period, there were no significant fluctuations in streamflow throughout the year. This can occur because, based on the manager, namely the Banjarnegara Regency Hydrology Unit Public Works Office, there are several irrigation weirs on the Merawu River, including at Clangap Station. This condition sets the amount of streamflow recorded for irrigation and agricultural purposes. These irrigation dams were not included in the modeling due to a lack of information on the location and dimensions of the dams. Furthermore, based on the RCP4.5 scenario, it is known that the average monthly streamflow starts to rise in March and reaches a peak between July and August. In the RCP8.5 scenario, it is known that the average monthly streamflow started to rise in January and decreased in June. There was also an increase in July, but an immediate decline occurred in August throughout the year. The average peak streamflow between the RCP4.5 and RCP8.5 scenarios is in the same range, which is around 120 m3/s. The RCP8.5 scenario shows a sharper angle of increase starting from January, which indicates that there is a rapid increase and can have implications for hydrometeorological disasters such as floods.

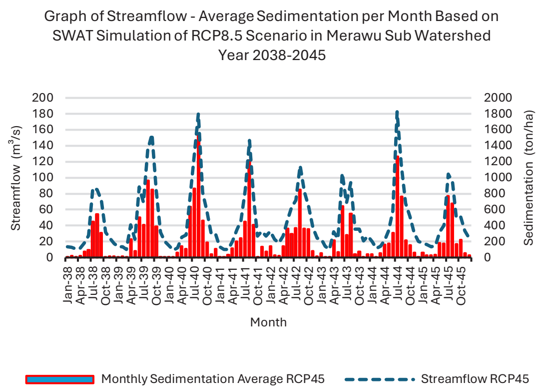


Fig.10. Graph of Streamflow - Average Sedimentation per Month Based on SWAT Simulation of RCP4.5 Scenario in Merawu Sub-watershed Year 2038-2045

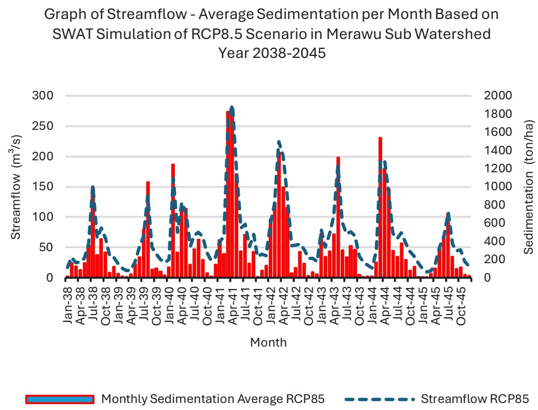


Fig.11. Graph of Streamflow - Average Sedimentation per Month Based on SWAT Simulation of RCP8.5 Scenario in Merawu Sub-Watershed Year 2038-2045.

Figure 10 and **Figure 11** show the linear pattern between monthly average sedimentation streamflow and monthly average sedimentation streamflow under each scenario. The average sedimentation in the RCP4.5 scenario increases in the middle of the year throughout the period range, namely in July. The largest sedimentation was recorded in July 2040, while the smallest occurred around October 2039 to March 2040. The RCP8.5 scenario shows a more inconsistent sedimentation pattern. The first increase in sedimentation was recorded in July 2038, followed by an increase in July 2039. There was no increase in sedimentation in July 2040. Further increases in sedimentation occurred in April of 2041 and 2044. However, there was no increase in sedimentation in April 2045.

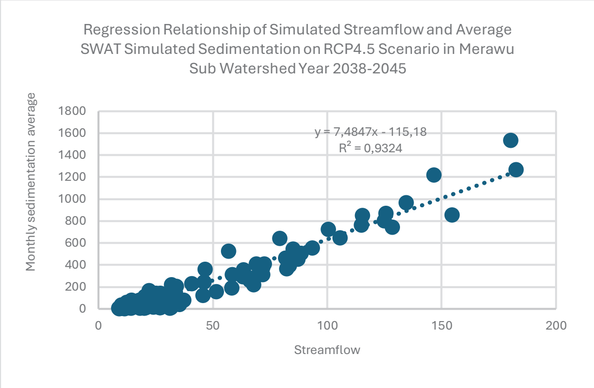


Fig.12. Regression Relationship of Simulated Streamflow and Average SWAT Simulated Sedimentation on RCP4.5 Scenario in Merawu Sub Watershed Year 2038-2045

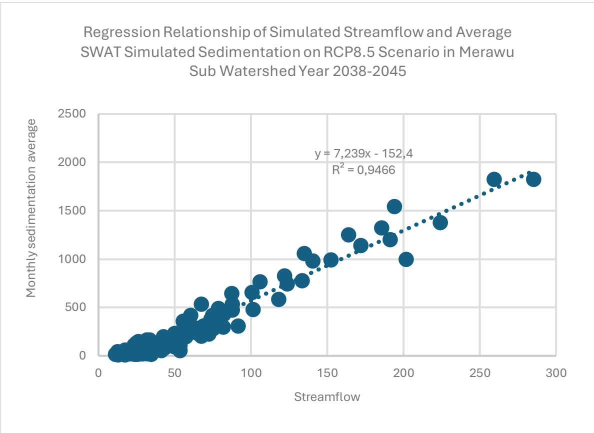


Fig.13. Regression Relationship of Simulated Streamflow and Average SWAT Simulated Sedimentation on RCP4.5 Scenario in Merawu Sub Watershed Year 2038-2045

Figures 12 and **Figure 13** show a strong linear relationship between average sedimentation and streamflow in each scenario. The regression equation in the RCP4.5 scenario shows that with every increase in streamflow by 1 m3/s, the average sedimentation increases by 7.4847 tons/ha. The R^2 value in the RCP4.5 scenario of 0.9324 indicates a very strong relationship between streamflow and sedimentation in the RCP4.5 scenario. While in the RCP8.5 scenario, it is known, based on the regression equation, that an increase of 1 m3/s will cause an increase in sedimentation of 7.239 tons/ha. The R^2 value of 0.9466 indicates that about 94.66% of the variability in average sedimentation can be explained by the variability in simulated streamflow. This indicates a very strong relationship between the two variables. Based on the regression equation, it is known that sedimentation in the Merawu Sub watershed is very sensitive to increases in streamflow.

Table 10. Percentage change of streamflow and sedimentation between baseline and climate change scenarios in Merawu Sub watershed

Object	***Mean Annual***				
	Baseline (2015 - 2022)	RCP45 (2038-2045)	RCP85 (2038-2045)	*Percentage of Change RCP45* (%)	*Percentage of Change RCP85* (%)
Streamflow (obs - sim) (m^3/s)	22.35	46.95	68.70	110.1	207.4
Sedimentation (sim) (ton/ha)	43.33	236.47	346.22	445.7	699

Based on **Table 10**, there are large differences in both the streamflow and sedimentation components. The percentage change in the average streamflow of the RCP45 and RCP85 scenarios against the *baseline* data is 110.1% and 207%, respectively. As for sedimentation, the increase was 445.7% and 699% for each scenario.

The considerable increase in streamflow and sedimentation is linear with the increase in rainfall based on climate scenarios, where there is an increase of 112% in the RCP4.5 scenario and 171% in the RCP8.5 scenario. This shows that based on the *baseline* model, the Merawu Sub watershed is highly vulnerable to climate change.

The study of climate change and its impact on the hydrological cycle is important to study in order to provide an overview of the conditions that will occur and become the basis for policymakers to determine mitigation direction measures [9]. In general, there are general local scale mitigation measures that can be taken in the face of climate change in the Merawu Sub watershed, such as adaptation in water resources management through infrastructure aspects by building small dams, reservoirs, and infiltration wells to reduce surface flow. SWC practices can also be applied to community-owned land and gardens to reduce erosion risk. Agroforestry can also be one of the ways to mitigate climate change, namely by becoming a GHG sink and reducing erosion through canopy interception on plantation land. Local-scale policies that can be taken care by establishing disaster risk zones and involving all aspects to increase awareness of climate change.

4 Conclusion

1. The results of this study indicate that climate change in both the RCP4.5 and RCP8.5 scenarios will have a significant impact on streamflow and sedimentation conditions in the Merawu Sub watershed. Based on the calculation of the percentage change between the baseline period (2015-2022) and the climate change scenario

(2035-2045) on climate variables, it is known that in the RCP4.5 scenario, there was an increase in rainfall by 112.22%, a decrease in maximum temperature by 24.97%, and a decrease in minimum temperature by 15.98%. As for the RCP8.5 scenario, there was an increase in rainfall of 171.19%, a decrease in maximum temperature of 21.46%, and a decrease in minimum temperature of 15.51%.

2. The calibrated SWAT model produces an R2 value of 0.68, NSE of 0.58, and PBIAS of -6.7. While model validation produces an R2 value of 0.56, NSE of 0.51, and PBIAS of 3.8. The resulting SWAT model is included in the good and satisfactory category.

3. Based on the calculation of the percentage change between the baseline period and the climate change scenario, it is known that in the RCP4.5 scenario, there was an increase in the average annual streamflow of 110.1% and an increase in the average sediment of 445.7%. While in the RCP8.5 scenario, it is known that there was an increase in streamflow of 207.4% and an increase in sedimentation of 699%. This shows a significant increase in streamflow and sedimentation due to climate change that occurs in the Merawu Sub-watershed. Increased streamflow can increase the risk of flooding and damage to infrastructure such as bridges and irrigation disruption. Meanwhile, increased sedimentation can accelerate the siltation of rivers and reservoirs and cause erosion and landslides to become more frequent.

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