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Effects of Land Cover Change on River Discharge Conditions in the Mamasa Watershed Using the SWAT Model

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ABSTRACT

Land cover changes occurring in a watershed will affect the ecosystem in that area. The Soil and Water Assessment Tool (SWAT) model is a tool that can be used to predict the impacts of land use on water, sedimentation, and chemical levels in a watershed. The Mamasa watershed is one of the sub-watersheds of the Saddang watershed, covering approximately 105,253 ha. This study aims to determine the land cover changes in the Mamasa watershed and their impacts on water discharge using the SWAT model. Several steps were undertaken, including image interpretation to obtain an overview of land cover in the years 2011, 2016, and 2020, which were then used to form Hydrology Response Units (HRU). Next, the SWAT model was run, involving delineating the watershed boundaries, defining HRU, integrating climate and HRU data, running SWAT simulations, and performing validation. The results of land cover classification from 2011 to 2016 showed an increase in secondary forest land by 4,896.68 ha (4.65%) and a decrease in shrubland by 9,500.60 ha (9.03%). The land cover classification from 2016 to 2020 indicated a decrease in secondary dry forest land by 6,349.43 ha (6.03%), with an increase in paddy field area by 3,141.92 ha (3%). These land cover changes led to a decreasing trend in water availability, as evidenced by increased discharge fluctuations from 16.50 to 21.65, in accordance with the SWAT simulation results, which increased from 6.73 in 2011 to 9.93 in 2020. The validation results of the SWAT model for the year 2011 showed a Nash-Sutcliffe Efficiency (NSE) value of 0.58 and and R2 value of 0.61. The validation for the year 2016 resulted in an NSE of 0.6 and an R2 of 0.68, while the validation for the year 2020 produced an NSE of 0.6 and an R2 of 0.65. All three validations fall under the satisfactory category, indicating that the SWAT model can be used to simulate the discharge of the Mamasa watershed.

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1. INTRODUCTION

A Watershed becomes a catchment area that significantly influences the water availability of a region, necessitating effective watershed management. Water availability refers to the amount of water needed for daily life or industrial purposes, sourced from rainfall, groundwater, rivers, and lakes. Watershed management involves optimizing land, vegetation, and water usage to mitigate the impacts of erosion and drought, enhance agricultural yields, and improve water availability.

DAS Mamasa is a sub-watershed of the Saddang Watershed, where Saddang Watershed is prioritized for restoration efforts. The Mamasa River spans two provinces West Sulawesi in its inlet reaches and South Sulawesi in its outlet reaches, specifically in the Pinrang Regency. In 2018, based on land cover assessment, the dominant land use in the Sub DAS Mamasa was dryland agriculture mixed with shrubland, accounting for 49.64% [1]. The land cover assessment in 2020 indicated a shift, with 60.32% of the Sub DAS Mamasa area being opened for

dryland agriculture, while primary and secondary forest cover accounted for 23.5%. These land cover changes will undoubtedly impact the communities residing around the Mamasa Watershed area in the future [8].
In the planning of watershed management, changes in land cover are crucial aspects to consider due to their influence on the hydrological conditions in both the upper and lower parts of the watershed. Optimal land cover conditions and the biophysical nature of the watershed significantly affect water management as they impact peak discharge and sedimentation. Poor watershed management, such as land cover changes in a watershed area, can lead to land degradation due to insufficient areas for water infiltration, resulting in high erosion, drought in the watershed area [7].
SWAT (Soil and Water Assessment Tool) is a software integrated with GIS, open-source in nature, and has been developed and utilized in various countries. The SWAT software is capable of analyzing river discharge for a specific area using relevant and representative data. In Indonesia, using the SWAT model requires calibration and validation aligned with available data, ensuring that the model's outputs match field conditions. This step is crucial due to the varying characteristics of each watershed, necessitating the consideration of model standard deviations and efficiency [6].
Based on the aforementioned description, this study aims to determine land cover changes in the Mamasa Watershed and their impacts on water discharge conditions within the watershed.
The purpose of conducting this research is to investigate the land cover changes in the Mamasa Watershed and their effects on water discharge within the Mamasa Watershed using the hydrological model SWAT (Soil and Water Assessment Tool).
The usefulness of this research is to providing valuable information to the government for the purpose of land cover management, aiming to safeguard water availability in the Mamasa Watershed.

2. MATERIALS AND METHODS

2.1 Time and Place
This research was conducted from October 2022 to May 2023 in the Mamasa Watershed, Pinrang Regency.

2.2 Tools
The tools used are Microsoft Excel, ArcGIS software, ArcSWAT.

2.3 Material
The data used are DEM, Landsat 7 image (2011) and Landsat 8 image (2016 and 2020), soil type map, climate data for 2011-2020 and discharge data for 2011-2020.

2.4 Research Procedure
The research procedures carried out in this study are.

2.4.1 Collection Data
Data collected for input to the SWAT model are secondary data in the form of climate data (rainfall, solar radiation, air temperature, and wind speed), land use maps (Landsat 7 and Landsat 8 images), discharge data, soil type data and slope maps..

2.4.2 Watershed Delineation
The process of delineating the boundaries of the Mamasa sub watershed is done with DEM data which is processed automatically by the SWAT model and will form the outer boundaries of the sub watershed in the SWAT model, namely the basin.

2.4.3 Land Cover
Land cover is obtained from the interpretation of Landsat 7 images in 2011 and Landsat 8 images in 2016 and 2020 for input to the SWAT model. Furthermore, image classification is carried out using unsupervised and supervised methods with the maximum likelihood tool to identify spectral classes which are divided into 10 classes (water bodies, bush, primary forests, secondary forests, habitation, dry land agriculture, dry land agriculture mixed with bush, savanna, rice fields and open land).

2.4.4 HRU (Hydrology Response Unit)
Hydrology Response Unit (HRU) analysis was conducted by overlaying the land cover map, soil type map and slope data. Each HRU formed contains specific information about the land including land cover, soil type and slope. The land cover and soil type data used in the HRU analysis are in ESRI raster format while the slope class classification is derived from the DEM dataset.

2.4.5 Weather Generator
Climatological data for rainfall is obtained from 3 rainfall measurement stations around the Mamasa watershed area, while data on temperature, relative humidity, solar radiation, and wind speed are obtained from

NASA Power. The climatological data is then processed using SWAT weather database software so that it can be connected to SWAT and as an input to the weather generator in SWAT.

2.4.6 Running SWAT

Running the SWAT model is done after the process of combining HRU with climatological data is complete. SWAT simulation can be determined by the year to be simulated and the time unit of the desired output. In this study, SWAT simulations were carried out using a 1-year period with 3 simulations, namely 2011, 2016 and 2020 with daily simulations. The type of output issued from this simulation is RCH output which contains the results of discharge data. Furthermore, running the SWAT model again 3 times using 2020 climate data on different land cover conditions so that the effect of land change on river discharge can be known.

2.4.7 Validation

Validation is done by comparing the discharge results from the model (simulated discharge) with the measured discharge in the field (observation discharge). To test the efficiency of the model, two methods were used, namely Nash Sutcliffe Efficiency (NSE) analysis.

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Q_{act} - Q_{sim})^2}{\sum_{i=1}^{n} \left(Q_{act} - \underline{Q}_{act}\right)^2} \qquad (1)$$

Qact is discharge actual (m3/s), Qsim is discharge simulation (m3/s), and _(Q) act is average discharge actual (m3/s). The efficiency of the Nash-Sutcliffe model is categorized into four classes as follows:
1. Excellent, if 0.75 ≤ NSE
2. Good, if 0.65 ≤ NSE ≤ 0.75
3. Pretty good, if 0.50 ≤ NSE ≤ 0.65
4. Not good, if NSE ≤ 0.50

In looking at the accuracy of the model output pattern with field observations, deterministic coefficients or linear equations are used:

$$R^2 = 1 - \frac{(X-\underline{X})^2 - (X-Y)^2}{(X-\underline{X})^2} \qquad (2)$$

X is the amount of observation discharge, _X is the average observation discharge and Y is the model calculation discharge. The calculation of R2 shows the evaluation of the feasibility of the model, if R2 is close to 1, there is a close relationship between the model predictions and field observations.

3. RESULTS AND DISCUSSION

3.1 Mamasa Watershed

Watershed is a catchment area for rainwater that falls into a river flow system so that it forms a watershed and is bounded by topography in the form of ridges where one watershed can have several sub-watersheds [11]. Mamasa watershed is a sub-watershed of the Saddang watershed which is located at an altitude of 62 meters above sea level until 2877 meters above sea level, where the upstream is located in Mamasa Regency and the downstream is in Pinrang Regency with an area of ± 105,253 ha. Most of the people in the downstream section are active as forest farmer groups but over time the community has switched to corn farmers. The land use change carried out by the community will have an impact on future water availability due to land clearing.

3.2 Land Cover Changes

Land cover change is obtained by interpreting Landsat 7 imagery (2011) and Landsat 8 imagery (2016 and 2020). There are 2 types of land cover classification methods, namely unsupervised and supervised. Unsupervised is a land cover classification without a training area while supervised is a classification method that first conducts sample training. In this research, classification is carried out with 2 methods, namely unsupervised and supervised methods. The unsupervised method is used to determine the initial description of land cover in the Mamasa watershed. The sample training points were taken from the 2019 land cover map from the Ministry of Environment and Forestry (KLHK). Classification uses 10 types of land cover, namely primary dryland forest, secondary dryland forest, open land, habitation, dryland agriculture, mixed dryland agriculture, savanna, rice fields, bush and water bodies.

The condition of the Mamasa watershed land cover in 2011 was obtained from the interpretation of Landsat 7 images, where the classification results showed that the Mamasa watershed area was dominated by mixed dryland agriculture 56.7%, secondary dryland forest 21% and bush 13.3% of the 8 classification results obtained can be seen in Figure 1. The classification of the image did not obtain the type of land use of habitation and open land. This is due to the influence of the low spatial resolution of the Landsat 7 image and the damage of the Landsat 7 image capture.

Figure 1. Land use map 2011.

Table 1. Land Use Mamasa watershed 2011.

Land Use Types	Area (ha)	Percent (%)
Primary dryland forest	4,545.59	4.32
Secondary dyland forest	22,078.7	20.98
Open field	0	0
Habitation	0	0
Dryland agriculture	1,907.21	1.81
Dryland agriculture mixed	59,719.13	56.74
Grassland	68.06	0.06
Rice field	2,440.45	2.32
Bush	13,961.62	13.26
Water body	532.24	0.51
Total	**105,253**	**100**

Land cover in 2016 was obtained by interpreting Landsat 8 images. The classification results show that the Mamasa watershed is dominated by mixed dryland agriculture 60%, secondary dryland forest 25.6% and bush 4.2% of the 10 types of classifications made can be seen in Figure 2. Land cover change from 2011 to 2016 shows an increase in secondary dryland forest area of 4.65%. This is because the type of Landsat 7 image used in the 2011 classification has a low spatial resolution while Landsat 8 has a medium resolution.

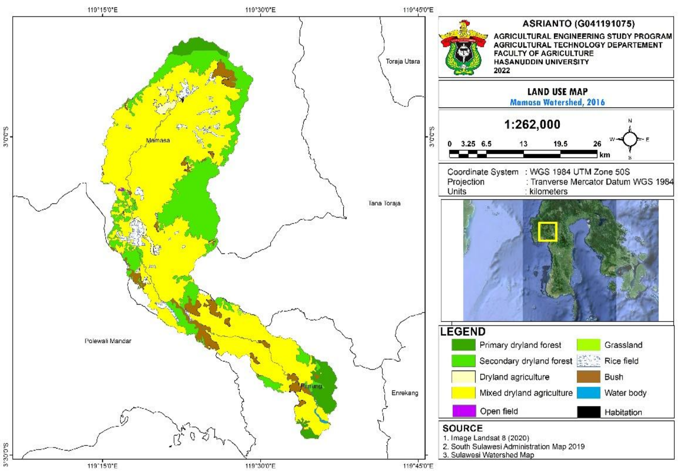

Figure 2. Land use map 2016.

Table 2. Land Use Mamasa watershed 2016.

Land Use Types	Area (ha)	Percent (%)
Primary dryland forest	4,996.21	4.75
Secondary dyland forest	26,975.59	25.63
Open field	42.95	0.04
Habitation	31.76	0.03
Dryland agriculture	1,283.37	1.22
Dryland agriculture mixed	63,618.34	60.44
Grassland	72	0.07
Rice field	3,223.61	3.06
Bush	4,461.02	4.24
Water body	548.16	0.52
Total	**105,253**	**100**

Land cover in 2020 is obtained from the interpretation of Landsat 8.The classification results show that the Mamasa watershed is dominated by mixed dryland agriculture 59.5%, secondary dryland forest 19.6%, and rice fields 6% of the 10 types of classification which can be seen in Figure 3. Land cover changes from 2016 to 2020 showed a decrease in the area of secondary dryland forest of 6.03% and bush of 0.41%. The increase in land use area occurred in the types of land cover of paddy fields 3%, habitation 1.64% and dry land agriculture 1.06%.

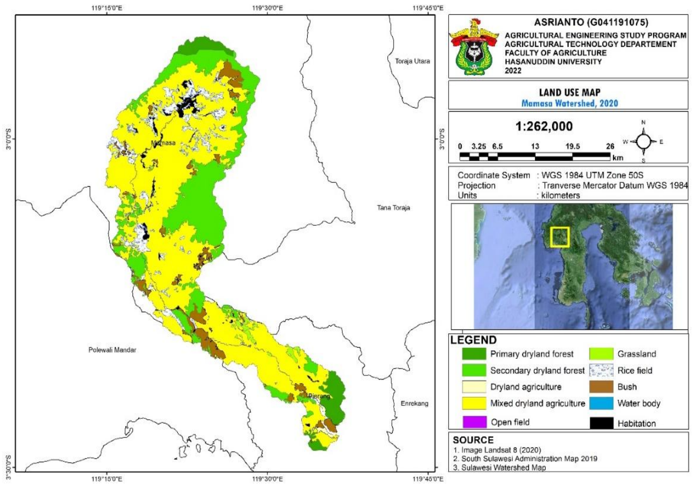

Figure 3. Land use map 2020.

Table 3. Land Use Mamasa watershed 2020.

Land Use Types	Area (ha)	Percent (%)
Primary dryland forest	4,756.77	4.52
Secondary dryland forest	20,626.16	19.60
Open field	4.1	0.01
Habitation	1,756.26	1.67
Dryland agriculture	2,394.96	2.28
Dryland agriculture mixed	62,639.89	59.51
Grassland	1,128.58	1.07
Rice field	6,365.53	6.05
Bush	4,888.79	4.64
Water body	691.98	0.66
Total	**105,253**	**100**

Table 4. Land cover changes.

Land Types	Area			Land Changes	
	2011 (ha)	2016 (ha)	2020 (ha)	2011-2016 (%)	2016-2020 (%)
Primary dryland forest	4,545.59	4,996.21	4,756.77	0.43	-0.23
Secondary dryland forest	22,078.70	26,975.59	20,626.16	4.65	-6.03
Open field	0	42.95	4.10	0.04	-0.04
Habitation	0	31.76	1,756.26	0.03	1.64
Dryland agriculture	1,907.21	1,283.37	2,394.96	-0.59	1.06
Dryland agriculture mixed	59,719.13	63,618.34	62,639.89	3.70	-0.93
Grassland	68.06	72	1,128.58	0	1
Rice field	2,440.45	3,223.61	6,365.53	0.74	3

Bush	13,961.62	4,461.02	4,888.79	-9.03	0.41
Water body	532.24	548.16	691.98	0.02	0.14
Total	**105,253**	**105,253**	**105,253**	**100**	**100**

3.3 Soil Type Map

Soil type maps are obtained from FAO (Food and Agriculture Organization) and then classified based on soil physical properties. Soil data input requirements in the SWAT model are soil data in the form of soil types and soil physical and chemical parameters. Soil types in the Mamasa watershed from FAO there are 3 types of soil combinations while the soil type map can be seen in Figure 4.

Table 5. Soil types classification.

No.	Soil Types	SWAT Code	Area (ha)	Percent (%)
1	*Tropaquepts; Tropofluvents*	*SOIL 39*	253.292	0.2
2	*Dystropepts; Tropudults; Humitropepts*	*SOIL 12*	59,681.715	56.7
3	*Rendolls; Eutropepts*	*SOIL 32*	45,317.992	43.1
	Total		**105,253**	**100**

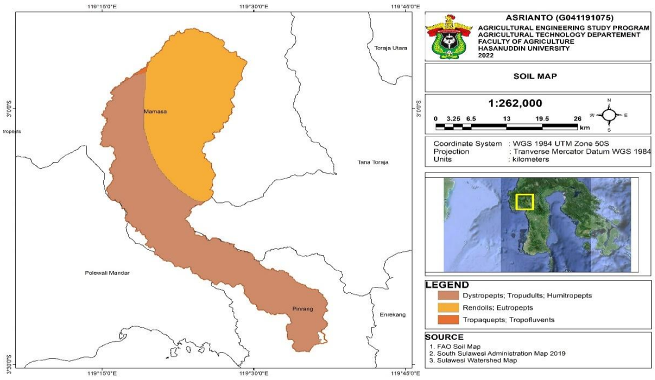

Figure 4. Soil type map.

3.4 Slope Map

The slope condition of the Mamasa watershed area is classified into 5 classes, namely flat, gentle, rather steep, steep and very steep. The classification of the Mamasa watershed slope class can be seen in Table 6, while the slope map can be seen in Figure 5.

Table 6. Slope classification.

No.	Slope (%)	Classification	Area (ha)	Percent (%)
1	0-8	Flat	4,573.75	4
2	8-15	Gentle	9,718.55	9
3	15-30	Rather steep	32,623.68	31
4	30-45	Steep	29,387.78	28
5	>45	Very steep	28,949.24	28
	Total		**105,253**	**100**

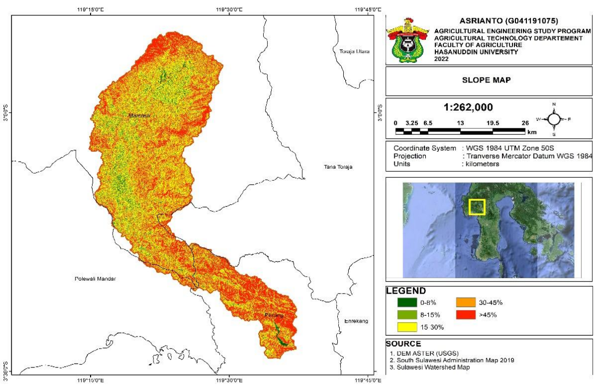

Figure 5. Slope map.

In general, the slope in the Mamasa watershed of Pinrang Regency is dominated by a rather steep slope class that reaches 31% with an area of 32,623.68 ha. This indicates that the Mamasa watershed in Pinrang Regency is located in a mountainous area or high area. According to [2], high topographic relief will produce rapid flow because there is the influence of topographic control that occurs as in mountainous areas.

3.5 HRU (Hydrology Response Unit)

A Hydrology Response Unit is the result of combining land use, soil type, and catchment slope. HRUs are characterized by the performance and distribution that occurs in each catchment [9]. In this study, the HRUs formed in 2011 were 486 units in 127 subbasin areas. In 2016, the HRUs formed were 518 units and in 2020 the HRUs were 526 units. The HRU distribution map can be seen in Figure 6.

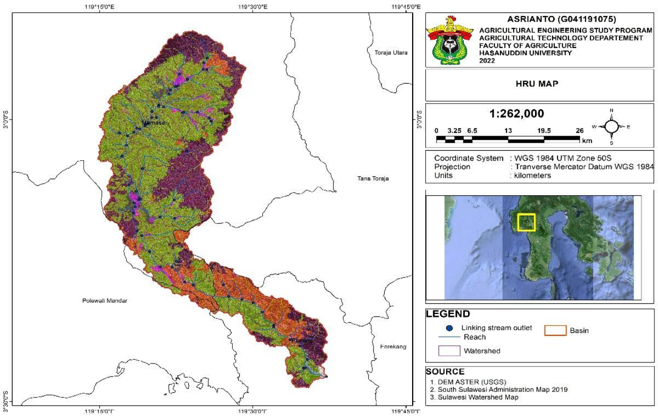

Figure 6. HRU map.

3.6 River Discharge

Changes in discharge that occur in rivers are influenced by rainfall and land cover. Rainfall and discharge have a directly proportional relationship if the value of rain falling in an area increases, of course the resulting discharge value will increase, provided that the physical conditions of the catchment area are the same. It can be seen in Figure 7. shows that the greater the rainfall, the greater the maximum discharge obtained. However, there are conditions where the amount of rainfall is low but the resulting discharge is not high enough, this can be caused by unrecorded rainfall. In accordance with the statement of [5] in his research that the occurrence of large discharge and small regional rainfall can be caused by local rainfall that is not recorded by rainfall posts. So that rain can be indicated that it does not occur evenly.

In evaluating the condition of a watershed can be seen in the discharge fluctuation indicator. Discharge fluctuations are obtained from the comparison between maximum discharge and minimum discharge. Discharge fluctuations in the Mamasa watershed have increased from 16.50 in 2011 to 21.65 in 2020. The increase in discharge fluctuations indicates a tendency to decrease water availability, due to the influence of changes in land cover that switch functions. In accordance with the statement of [4] states that the high value of discharge fluctuations indicates the amount of surface flow that occurs in the rainy season and the flow discharge in the dry season is very small (indicating drought).

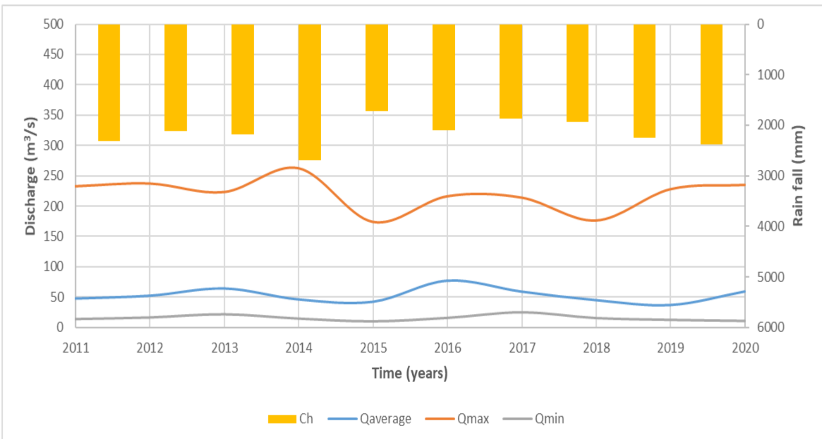

Figure 7. Discharge and rainfall relationship.

3.7 Simulation and Validation

After the simulation is carried out, validation is then carried out on each running result. Validation aims to prove that a process or method can provide appropriate results. The validation process is carried out by comparing daily data on actual discharge with simulated discharge in 2011, 2016 and 2020. Validation is done using NSE and R2, NSE analysis is used to determine the difference in distance between simulated discharge and actual discharge where the NSE value is closer to 1 then the simulation is close to the situation in the field. R2 analysis is used to measure the goodness of fit of a regression equation, so that the percentage of total data variation in the dependent variable explained by the independent variable is required to have the same characteristics or distribution fluctuations [3].

The validation results in 2011 showed a Nash-Sutcliffe Efficiency (NSE) value of 0.58 (quite good) and R2 of 0.61. The validation results can be seen in Figure 8 and Figure 9.

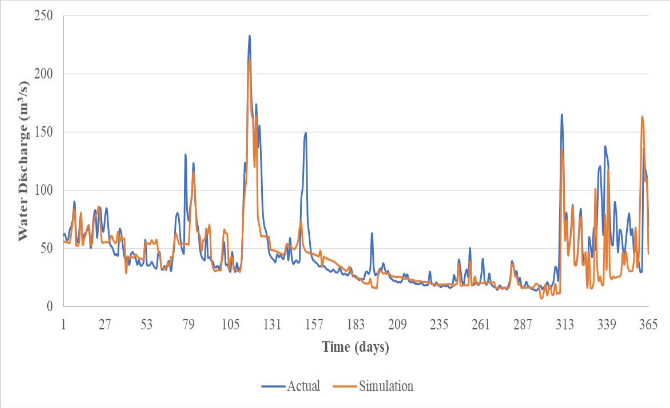

Figure 8. Comparison of actual and simulated discharge 2011.

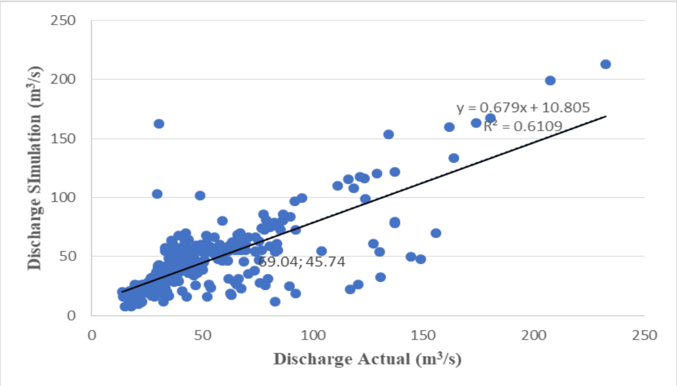

Figure 9. Regression analysis of actual and simulated discharge 2011.

The 2016 validation showed a Nash-Sutcliffe Efficiency (NSE) value of 0.6 (pretty good) and R2 of 0.68. The validation results can be seen in Figure 10 and Figure 11.

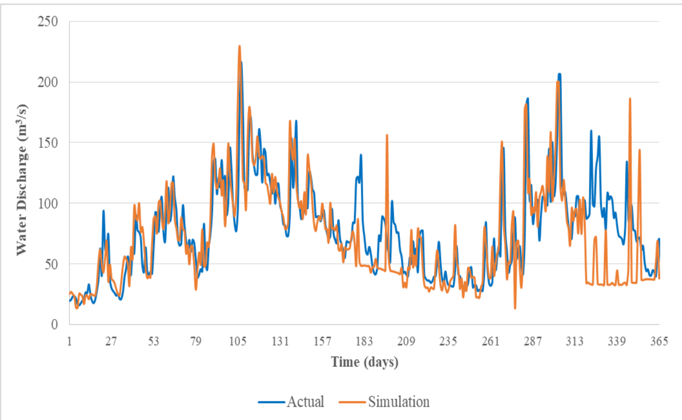

Figure 10. Comparison of actual and simulated discharge 2016.

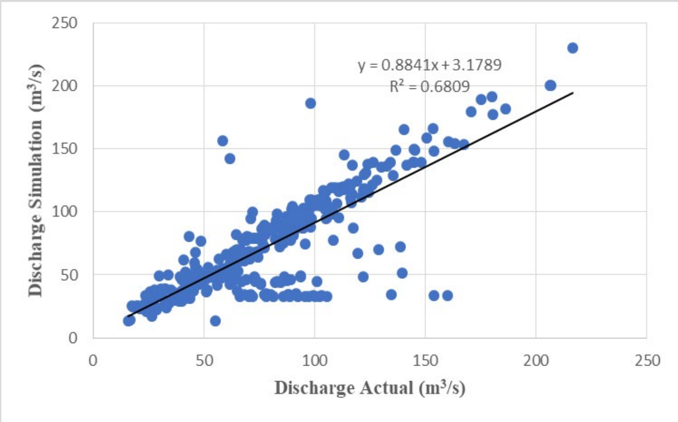

Figure 11. Regression analysis of actual and simulated discharge 2016.

The 2020 validation shows a Nash-Sutcliffe Efficiency (NSE) value of 0.6 (pretty good) and R2 of 0.65. The validation results can be seen in Figure 12 and Figure 13.

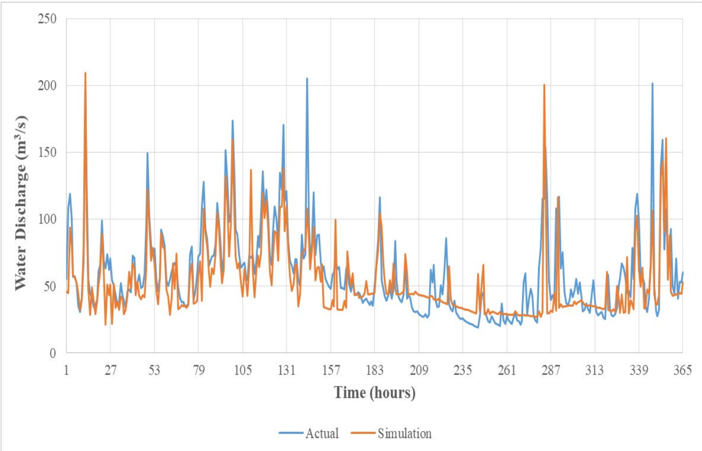

Figure 12. Comparison of actual and simulated discharge 2020.

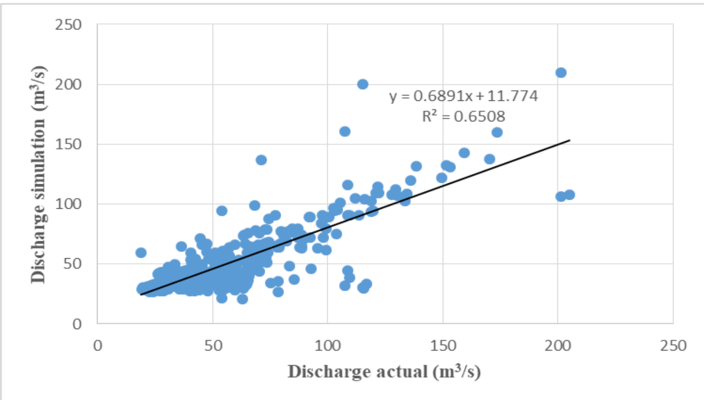

Figure 13. Regression analysis of actual and simulated discharge 2020.

Of the three NSE analyses in 2011, the one obtained was lower than in 2016 and 2020 due to the influence of inaccurate input of land cover types in 2011, which affected the output of simulation results. The NSE value obtained is in the satisfactory category and the R2 value ≥ 0.5, so the SWAT model can be used to simulate discharge in the Mamasa watershed. This is in accordance with the statement [5] that the validation of the SWAT model if the NSE and R2 values in the satisfactory category can be said to be valid.

3.8 Effect of Land Cover Change on River Discharge

After validation, running the SWAT model again using only climate data in 2020 while the land cover used is 2011, 2016 and 2020 so that running is done 3 times on different land cover conditions with the same rainfall conditions so that it can be seen how the influence of land cover on river discharge conditions.

Table 7. SWAT simulation results on each land cover conditions.

Land Use Years	Land Changes	Rainfall (mm)	Q_{max} SWAT (m^3/s)	Q_{min} SWAT (m^3/s)	Q_{max} SWAT / Q_{min} SWAT
2011	-	2,381.56	195.51	29.03	6.73
2016	Primary dry forest-Secondary dry forest Secondary dry forest-Mixed dry farming Bush-Mixed dry farming Mixed dry farming-Habitation	2,381.56	195.92	27.08	7.23
2020	Secondary dry forest-Mixed dry farming Secondary Dry Forest-Habitation Mixed Dry Farming-Habitation Mixed Dry Farming-Rice field Mixed Dry Farming-Habitation Mixed dry farming-Dry farming	2,381.56	209.6	21.11	9.93

Simulation results can be seen in Table 8. Where 2011 to 2016 shows changes that only occur in the value of Qmin which has decreased from 29.03 m3/s to 27.08 m3/s this is due to secondary dryland forest land cover which has increased in area, but a decrease in area also occurs in bush which become mixed dryland agriculture. Simulations in 2016 to 2020 showed an increase in Qmax 195.92 m3/s to 209.6 m3/s and a decrease in Qmin 27.08 m3/s to 21.11 m3/s. This is because in the upstream part there is a decrease in the area of secondary dry forest and mixed dry agriculture which is converted into rice fields, habitation and dry land agriculture. This is in accordance with the statement of [10] that the conversion of forest land into seasonal agricultural land will result in increased potential for water (floods, landslides and droughts).

4. CONCLUSION

Based on the results of the study, the following conclusions were obtained:

1. The results of the image classification showed land cover changes from 2011 to 2016, the addition of secondary dryland forest by 4,896.68 ha (4.65%) and a decrease in bush by 9,500.60 ha (9.03%). The classification of land cover from 2016 to 2020 shows that secondary dryland forest decreased by 6,349.43 ha (6.03%), the addition of land use area occurred in rice fields 3,141.92 ha (3%).
2. Land cover changes that switch functions from secondary dry forest, bush to rice fields, dry land agriculture, and habitation cause water availability to tend to decrease, this can be seen in the fluctuation of discharge which increases from 16.50 in 2011 to 21.65 in 2020, in accordance with the comparison of Qmax and Qmin SWAT simulation which is increasing from 6.73 in 2011 to 9.93 in 2020.
3. The 2011 validation results showed a Nash-Sutcliffe Efficiency (NSE) value of 0.58 and R2 of 0.61, the 2016 validation results showed an NSE of 0.6 and R2 of 0.68 and the 2020 validation NSE of 0.6 and R2 of 0.65, this indicates that the SWAT model can be used in simulating Mamasa watershed discharge.

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