MODEL OF SOIL AND WATER CONSERVATION MEASURES APPLICATION BASED ON DISTRICT SPATIAL PLANNING IN MAMASA WATERSHED, SOUTH SULAWESI

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Abstract: *Depletion of watershed carrying capacity cannot be omitted from mismanagement of the watershed. The integration between SWAT model and remote sensing data are able to identify, assess, and evaluate watershed problem as well as a tool to apply the mitigation of the problem. The aim of this study was to arrange the scenario of watershed management, and decide the best recommendation of sustainable watershed management of Mamasa Sub Watershed. The best recommendation was decided by hydrology parameters, e.i. surface runoff, sediment, and runoff coefficient. Hydrology characteristics of Mamasa Sub Watershed was analyzed based on land use data of year 2012 and climate data for period of 2010-2012. The scenarios were application of bunch and mulch in slope 1-15%; bunch terrace (scenario 1), mulch and strip grass in slope 15-25% (scenario 2), alley cropping in slope 25-40% (scenario 3), and combination scenario 1, 2, 3 with agroforestry in slope > 40% (scenario4). Surface runoff value of Mamasa Sub Watershed is 581.35 mm, while lateral flow, groundwater flow, runoff coefficient, and sediment yield of 640.72 mm, 228.17 mm, 0.29, and 187.213 ton/ha respectively. Based on the scenario's simulation, the fourth scenario was able to reduce surface runoff and sediment yield of 33.441% and of 51.213%, while the runoff coefficient declined to 0.194. Thereby, the fourth scenario is recommended to be applied in Mamasa Sub Watershed so that the sustainability in the watershed can be achieved.*

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1. INTRODUCTION

Mamasa watershed potentially degraded due to the topography of its area which was dominated by slopes >40% (Department of Forestry, 2010). Cultivation activities, encroachment, illegal logging, over-harvesting, tillage without conservation practices, and the other activities of the community in the forest area were also to be the factors that contributed to land degradation (Department of Forestry, 2010). As 66.17% (76,497 hectares) area of Mamasa watershed is categorized as degraded land. Previous research showed that amount of erosion in the Mamasa watershed in 2010 was amounted to 19,561,011 tons/year. The amount of erosion indicated the amount of sediment that occurs in the Mamasa watershed. The volume of water in reservoirs of Bakaru hydroelectric power is decreasing in average of 301,707 m^3/year.

Mamasa watershed management underscore the need for planning, monitoring and evaluation in order to ensure the preservation of water distribution throughout the year and to minimize the increase in surface runoff or sediment. The assessment can be done by using a model such as described in previous review studies (Srinivasan et al., 2010; Cibin et al., 2013; Daniel, 2011; QIU et al., 2012; Himanshu et al., 2016; Shi et al., 2017). From the literatures, it is known that SWAT hydrologic models are simplification representations of actual soil, land use, topographic, climate, and other interactions that occur within natural hydrologic and environmental systems that can be used to analyze runoff, sediment, and water balance. The model also can be effectively and efficiently used for simulating a various of conditions that could not be possible to measure in such complex conditions. Model also can be chosen base on watershed representation and spatial scale (Daniel, 2011).

One model that can be used is SWAT hydrological model (Arnold et al., 2012; Neitsch et al., 2011; Suryavanshi et al., 2017) it is widely used by researchers, government agency and other users. SWAT was developed to predict the impact of land management practices on water, sediment, agricultural chemical yields that enter the river in a complex watershed with varying soil, land use and management conditions over a long time period. Several studies (Moriasi et al., 2011; Sunandar & Suhendang, 2014; Yusuf et al., 2016) showed that SWAT was able to described the impacts of land management on hydrological characteristics of watershed and successfully used in scenario analysis of variety conditions of climatic and environmental worldwide (Douglas-Mankin et al., 2010; Gassman et al., 2014; Krysanova & White, 2015). The model also able to analyze and to create some scenarios including best management practices (soil and water conservation technique), climate change, and land use change in a watershed. Applying scenario of best management practices such as nutrient management, constructed wetland, and filter strip in Big Ditch Watershed, indicate that the average nitrate-N load reduce of 15.8%, 17.1%, 9.9%, respectively (Getahun & Keefer, 2016). Application of conservation crop rotation and no-till is the best scenario in reducing sediment load in St. Joseph River watershed, while the conservation crop rotation and cover crop reduced the big amount of nutrients (Her et al., 2016). Jang et al., (2017) research showed that application of BMP in Haean highland agricultural catchment of South Korea such as vegetation filter strip, fertilizer control, and rice straw mulching could reduce the sediment load around 16-34.8%, 4.9-16.4%, and 3-14.1%, respectively. The other research by Liu et al., (2016) indicated that application of nutrient management, buffer strip, cover crop, and wetland restoration in Grand River watershed, Southern Ontario, reduce the sediment at the watershed outlet ranges between 0 – 5.54%, Total Phosphorus from 6.28 up to 41.32%, and Total Nitrogen between 1.97 – 18.54%.

The aim of this study was to (1) estimate the hydrological characteristics including surface flow, lateral flow, base flow, and sediment yield in ungauged watershed of Mamasa using SWAT model, (2) arrange several scenarios for the best management practices in Mamasa watershed. This research is important for the stakeholders in Mamasa Watershed because the result will be used to evaluate the condition of Mamasa Watershed.

2. DATA AND METHODS

Mamasa watershed is one of multifunctional watershed on the island of Sulawesi, Indonesia. The watershed is source of irrigation water, raw water for the people who live around it and hydroelectric power (Bakaru Power Plant) (Department of Forestry, 2010). Geographically, Mamasa watershed is located between 119°13'-120°21' E and 2°43'-3°46' S and administratively between Tana Toraja, Pinrang, Enrekang, Polewali Mandar, and Mamasa regency, which is located at West Sulawesi (upstream of the watershed) and South Sulawesi Province (downstream of the watershed), Indonesia. The total area of Mamasa watershed is 115,607 ha. The study location is presented in Figure 1.

2.1. Data

Materials and data required in this study are: a) DEM (Digital Elevation Model, 30 x 30 m) map, b) land use map in 2014, c) soil map, d) daily climate data (rainfall, solar radiation, relative humidity, wind speed and maximum and minimum air temperature). Primary data of soil characteristics was obtained from the laboratory analysis of soil samples for chemical and physical parameters of the soil (soil texture, bulk density, available water content, permeability, soil erodibility value and soil organic matter content). Field observations included the measurement of effective depth, thickness of the horizon, soil structure, the pattern of crop management, conservation techniques, and river characteristic (roughness of the river and channel cover).

Figure 1. The Study Location

2.2. Method

Analysis of the hydrological characteristics of Mamasa watershed was performed by using SWAT model version 2012 (SWAT2012) with the ArcGIS interface (ArcGIS 10.1). There are four (4) steps in SWAT model: delineate watershed, sub watershed, and stream network using Digital Elevation Model (DEM) data (1), generate Hydrology Response Unit/HRU in watershed using the information both map and characteristics of soil, land use, and slope (2), linking the HRU with climate data, and write the table input of model (3), and running the simulation for the certain year (4). The model analyzed the hydrology by using some equations consisted of SCS Curve Number, kinematic storage model, and the steady-state response of groundwater flow to recharge equation. The formula of SCS Curve Number is (equation 1):

$$\text{Qsurf} = \frac{(Rday - I_a)^2}{(Rday - I_a + S)} \quad \text{...} \quad (1)$$

where Qsurf is amount of surface runoff volume in day i (mm), Rday is amount of precipitation in day i (mm), Ia is initial loss of surface storage, interception, and infiltration (mm), and S is retention parameter (mm). The kinematic storage model to calculate the lateral flow is (equation 2):

$$\text{Qlat} = 0.024 \left(\frac{2.SW_{ly,excess}.K_{sat}.slp}{\Phi_d.L_{hill}} \right) \quad \text{...} \quad (2)$$

Qlat is lateral volume that flow into the main channel in day i (mm), SWly,excess is excessive water in soil profile (mm), Ksat is saturated hydraulic conductivity (mm/hour), slp is slope (mm), Φd is soil porosity (mm/mm), and Lhill is length of slope (m).

The steady-state response of groundwater flow to recharge equation is (equation 3):

$$\text{Qgw} = \frac{8000.K_{sat}}{L_{gw}^2} xh_{wtbl} \quad \text{...} \quad (3)$$

where Qgw is ground water volume (mm), Ksat is saturated hydraulic conductivity (mm/hour), L_{2gw} is distance between sub watershed to the main channel (m) and hwtbl is height of water table (m).

The contribution of total runoff (amount of Qsurf, Qlat, and Qgw) and sediment to the sub watershed were used to identify the degraded sub watershed in Mamasa watershed. And then, the scenarios of soil and water conservation techniques were applied in the sub watershed to improve its condition. The scenarios are presented in Table 1.

Table 1. Scenario of land management and soil and water conservation technique

No.	Land Use Type	Conservation Technique		Scenario			
		Slope (%)	Technique	1	2	3	4
1	Upland agriculture, plantation/unirrigated agricultural field mixed with bushes	0-15	Bunch and mulch	√	√	√	√
2	Upland agriculture, plantation/unirrigated agricultural field mixed with bushes	15-25	Bunch terrace, mulch, and strip grass		√	√	√
3	Upland agriculture, plantation/unirrigated agricultural field mixed with bushes	25-40	*Alley cropping* and silt pilt			√	√
4	Upland agriculture, plantation/unirrigated agricultural field mixed with bushes	>40	Agroforestry				√

3. RESULTS AND DISCUSSION

3.1. Stream Network, Sub Watershed, and HRU

The results from the first step in running the SWAT model are stream network, sub watershed, and watershed boundary. There are 16 sub watersheds in Mamasa watershed, namely sub watershed 1 until sub watershed 16. Sub watershed 1 is located in upstream, and sub watershed 16 is located in the downstream. The establishment of sub watershed was depended on area of threshold that used to delineate the stream network. The threshold is 2,500 ha, which is generates only the main channel in Mamasa watershed. River network and sub watershed map is presented in Figure 2.
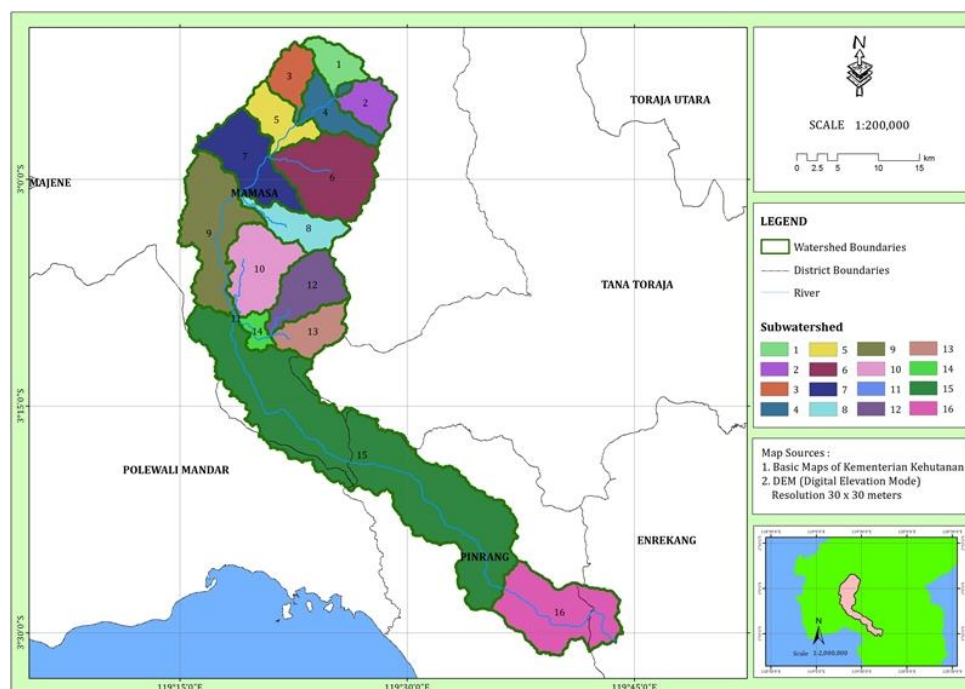

Figure 2. River Network and Sub Watershed Map

The results from the second step are HRUs. HRUs are small analysis unit in SWAT model that is derived from overlay the soil, land use and slope map and its characteristics. So, each HRU has uniquely information about combination of soil, land use, and slope. The total amount of HRUs in a watershed is depends on threshold which is used for each map. The HRUs in Mamasa watershed were performed using threshold by percentage method (0%) so that generated 626 HRUs in Mamasa watershed. The spatial distribution of HRUs is presented in Figure 3.
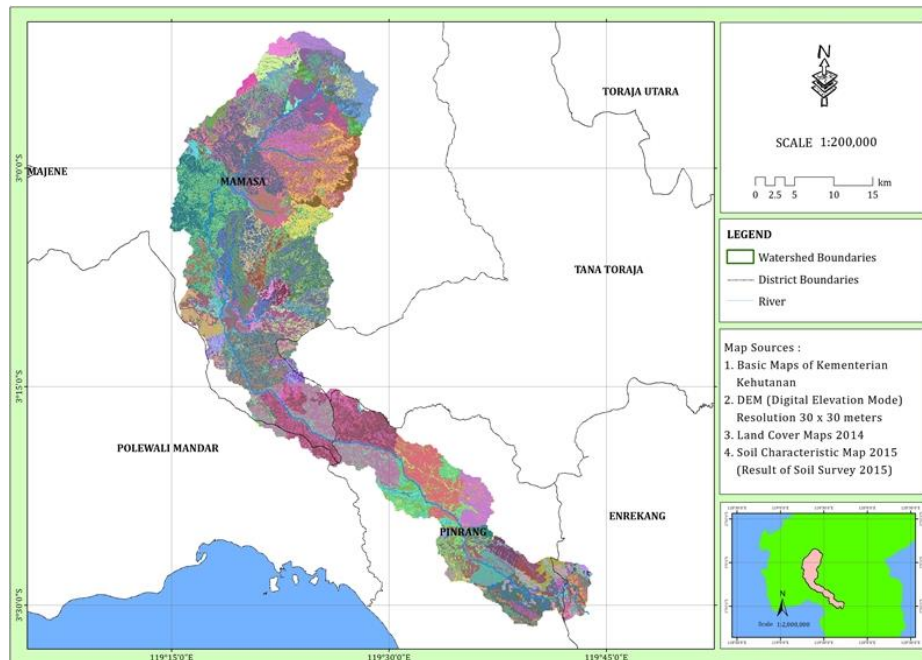
Figure 3. HRUs Distribution in Mamasa Watershed

3.2. Effect of Land Use to Hydrological Characteristics in Mamasa Watershed

Hydrological characteristics of Mamasa watershed is presented in Table 2. The result showed that the highest surface runoff in Mamasa watershed was occur in December (304.92 mm) as 38.16% from the rainfall in the same month, while the lower was occur in October as 4.47% from the rainfall. The highest contribution of the rainfall to lateral flow was occurred in October as 37.74% and the highest base flow occurred in August as 28.65%. Flow discharge of Mamasa watershed is presented in Figure 4. Even this model was not calibrated because Mamasa watershed is the ungauged watershed, but the result can be used to analyze the condition of watershed due to the input detail field data of soil characteristics into the model and adjusted sensitivity parameter base on watershed characteristics so the uncertainty from model can be reduced. The same study in ungagged basin of Central Vietnam showed that surface runoff was occurred in October with approximately 764 mm and the highest sediment yield as 580 ton per hectare (Emam et al., 2016). But this study still calibrated using the regionalization river discharge and showed the Nash Suttcliffe efficiency range between 0.67-0.73.

From result in Table 2, then flow regime and runoff coefficient were calculated for Mamasa watershed. The flow regime coefficient was 40.26 which categorized as lower rank (Regulation of Ministry of forestry RI No. P.61/Menhut-II/2014), while the runoff coefficient was 0.29 (lower category). This value indicates that Mamasa watershed is still in good condition. But, the dominant steep slope in this watershed remains as the cause of the damage in the watershed.

Tabel 2. Hydrological Characteristics in Mamasa Watershed

Month	Average Rainfall	Surface Flow	Lateral Flow	Base Flow	Sediment Yield
	mm	-------------------- mm -----------------			tons/ha
January	112.33	26.48	36.85	4.1	15.19
February	233.51	71.28	84.26	17.51	35.18
March	181.54	53.76	63.9	39.34	28.8
April	315.35	111.04	99.92	35.72	72.71
May	216.71	73.86	61.77	41.66	14.13
June	118.28	22.21	37.04	25.35	2.14
July	186.36	59.74	44.18	15.8	9.02
Augustus	17.42	0	4.69	4.99	0
September	45.18	2.89	13.09	0.74	1.13

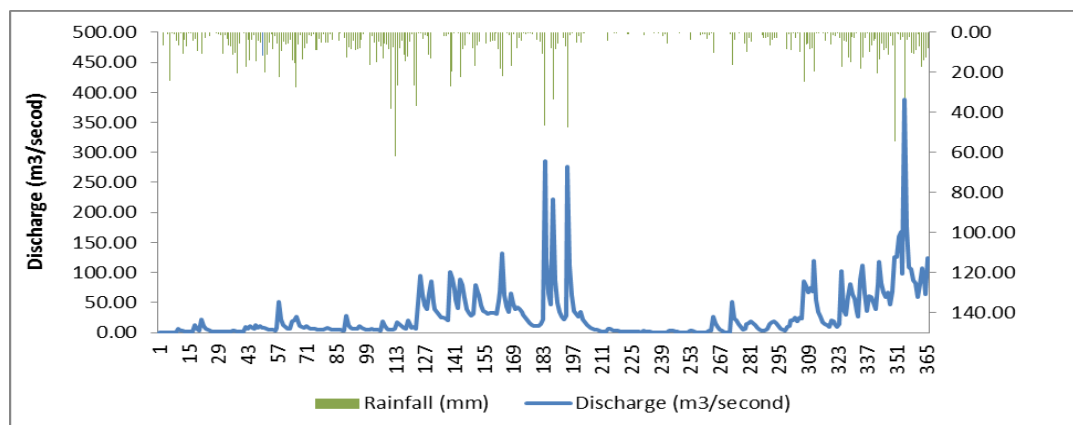|					
October	80.7	3.61	30.46	0.23	0.11
November	180.5	40.13	66.75	5.34	1.66
December	304.92	116.35	97.81	37.39	7.54
Total	1,992.8	581.35	640.72	228.17	187.61

Figure 4. Daily Discharge of Mamasa Watershed in 2012

3.3. Degraded of Sub Watershed in Mamasa

Degraded Sub watershed was determined based on contribution of total runoff and total sediment to the Sub watershed. The total runoff and total sediment in Mamasa watershed is presented in Table 3 and spatially presented in Figure 5 and Figure 6. Based on the data, Sub watershed 15 was the sub watershed that most degraded with the contribution of total runoff and total sediment to its Sub watershed as 46% and 59.75%, respectively. The second degraded sub watershed was sub watershed 16, followed by sub watershed 6. If the Mamasa watershed is not well-managed, it is possible that the degradation in Mamasa watershed will increase. In order to decrease the degradation in Mamasa watershed, the management planning especially related to soil and water conservation is arranged for this watershed.

Table 3. Total Runoff and Sediment from SWAT Model in Sub watershed, Mamasa watershed

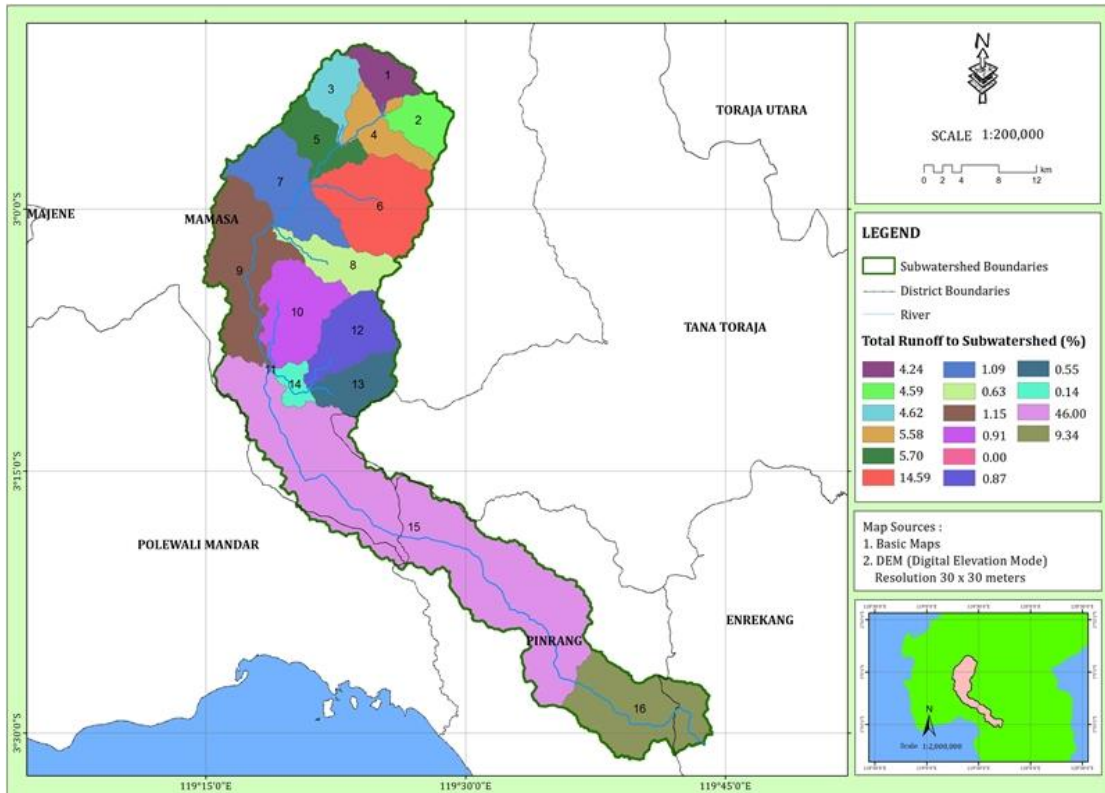| Sub watershed	Area (ha)	Total runoff (mm)	% total runoff to Sub watershed	Total sediment (tons/ha)	% sediment to Sub watershed
1	2,842.50	2,233.84	4.24	2,110.90	0.66
2	3,085.40	2,229.12	4.59	1,690.02	0.58
3	3,082.00	2,245.47	4.62	1,776.87	0.61
4	3,790.00	2,208.13	5.58	1,732.80	0.73
5	3,858.10	2,215.19	5.70	1,881.14	0.80
6	9,798.50	2,231.12	14.59	1,812.57	1.96
7	7,379.00	220.79	1.09	55.88	0.05
8	4,035.00	233.12	0.63	47.72	0.02
9	10,568.00	163.30	1.15	94.56	0.11
10	6,985.80	195.57	0.91	173.69	0.13
11	4.09	42.28	0.00	4.59	0.00
12	5,524.00	236.64	0.87	142.25	0.09
13	3,842.70	212.61	0.55	119.41	0.05
14	1,373.50	153.91	0.14	247.079	0.04
15	38,940.00	1,770.17	46.00	13,880.14	59.76
16	10,935.00	1,280.19	9.34	28,462.72	34.41
Total	116,043.59	17,871.45	100.00	54,232.34	100.00

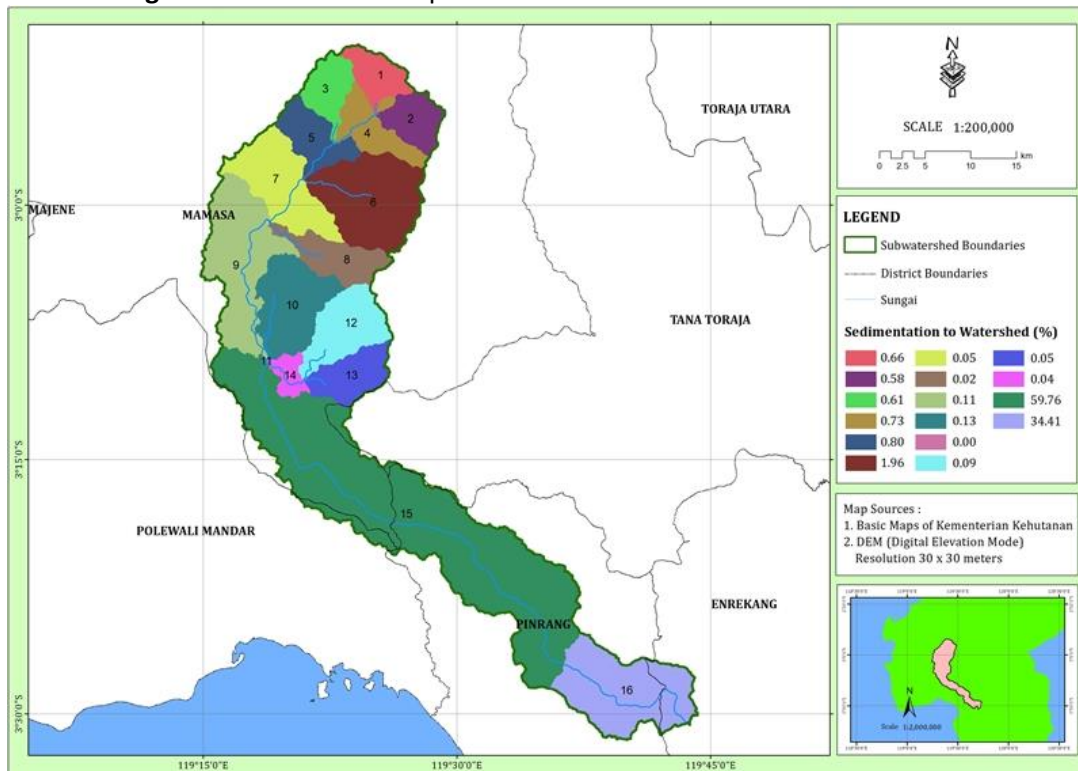**Figure 5**. Total Runoff Map from Sub Watershed in Mamasa Waterhsed

Figure 6. Sediment Yield from Sub Watershed in Mamasa Watershed

3.4. Simulation of Land Management and Soil and Water

The arrangement of scenario of land use is done to achieve the best management practices that can minimize the runoff and sediment which occur in Mamasa watershed. Scenario of land management and soil and water conservation were applied based on land use 2014 and in agriculture land because the highest contribution from it to the erosion process in a watershed. The goal of conservation technique

application is to increase soil capability in infiltrate the rain water, thus it cannot contribute to surface runoff, immediately. The scenarios were also arranged to ensure the preservation of water distribution in wet and dry season. The scenarios are presented spatially in Figure 7.
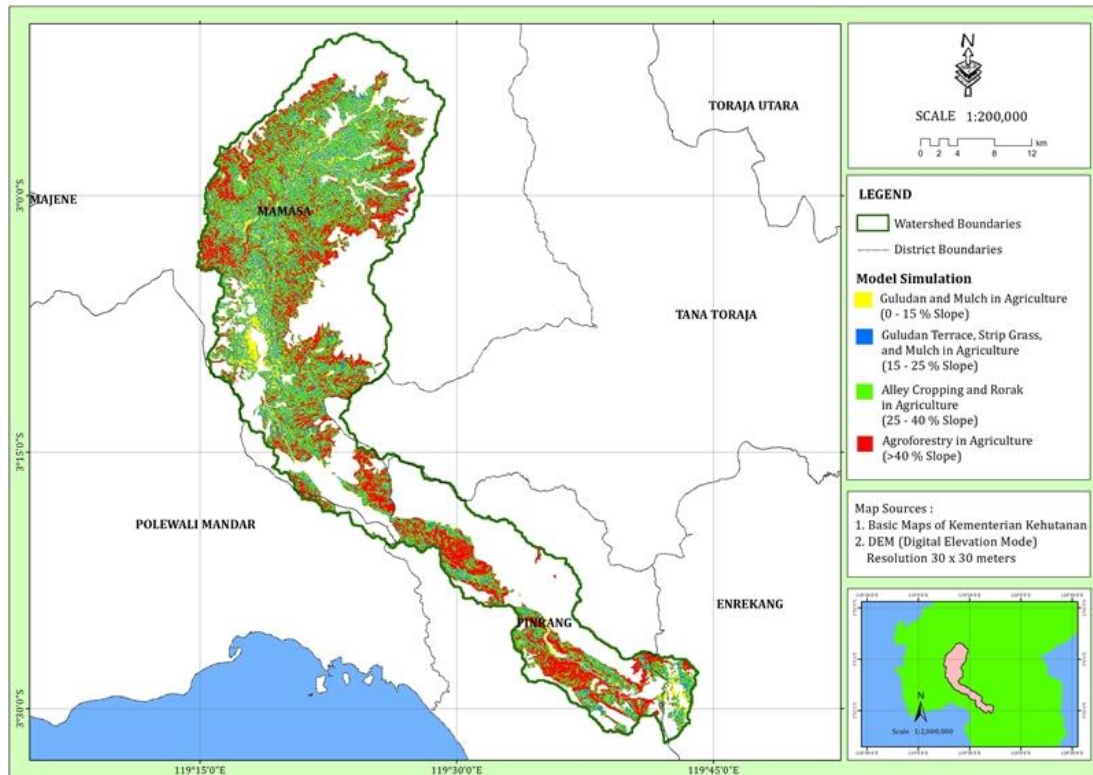

Figure 7. Map of Scenario Application in Mamasa Watershed

The results of scenarios simulation to characteristics hydrology in Mamasa watershed is presented in Table 4. The conservation technique application in SWAT simulation is able to decrease surface runoff in Mamasa watershed and also decrease the runoff coefficient. Decreasing surface runoff, the increasing lateral flow and base flow from the scenario. Surface runoff was decrease approximately between 2.48 – 33.44%, while the lateral flow and base flow were increase as much as 0.19 – 20.38%, and 1.96 - 2.58%. The highest decreasing of surface runoff was generated from scenario 4, which was the combination of whole scenario so the effect of conservation techniques to be maximum.

Table 4. Hydrological Characteristics from Scenario Application

Scenario	Rainfall	Surface flow	Lateral flow	Base flow	C value	Sediment yield
		--------------------mm--------------------				tons/ha
Existing	1992.8	581.35	640.72	228.17	0.292	332.96
Scenario 1	1992.8	566.95	641.91	234.06	0.284	330.28
Scenario 2	1992.8	550.55	654.75	233.4	0.276	321.77
Scenario 3	1992.8	480.62	702.71	232.65	0.241	290.13
Scenario 4	1992.8	386.94	771.33	227.45	0.194	212.97

Runoff coefficient of existing condition in Mamasa watershed as 0.29 was decrease about 2.74 – 33.56% after the watershed management scenario was applied. The highest decreasing of runoff coefficient was achieved by applying scenario 4. The combinations of whole scenario are able to increase the effectiveness of applied conservation technique. Mulch can decrease the rainfall energy so that it cannot destroy the soil structures, decrease the speed and amount of surface runoff thus can reduce surface runoff energy. Mulch also reduces the evaporation and keeps the water content in soil.

The function of strip grass application to preserve the river sustainability is achieved by holding and capturing soil eroded/mud as well as nutrient and chemicals including pesticide from agricultural land. The hedge plant on alley cropping system functioned to hold water, fertilize the soil, minimizing the erosion and landslide, and increasing the microorganism activity. Silt pilt was constructed to catch the runoff and soil eroded so that the water can infiltrate to the deep soil and reduce erosion.

The simulation results also indicate a decrease in sedimentation. Simulation of scenario 4 was able to reduce sediment up to > 40%. Decreasing in sediment will be higher if the agricultural land is mostly applied by the conservation techniques. Thus, it can be said that the implementation of appropriate conservation techniques and appropriate to the circumstances in the field are effective in reducing runoff and sediment. This result is linier with other studies about best management practices. Application of vegetation filter strip (VFS) in Haean highland agricultural catchment of South Korea is the best way to reduce the sediment load, The VFS was applied in 3 different ways are vegetative filter strip with 1m, 3m, and 5m. The VFS5m is the best technique in reducing the sediment load in watershed outlet approximately 34.8%, while the VFS1m and VFS3m reduce sediment as 16.0 and 22.1%, respectively. However, the techniques fertilizer control, and rice straw mulching only reduce the sediment load around 4.9-16.4%, and 3-14.1%, respectively (Jang et al., 2016). The decreasing of sediment load came from the discharge load contribution in upland crop areas. Another research by Liu et al. (2016) indicated that application of buffer strip and cover crop in upland fields are the best techniques in reducing the sediment load approximately 5 − 13% compare to the initial condition, while the whole scenario including nutrient management, buffer strip, cover crop, and wetland restoration only reduce sediment as much as 0 − 5.54% in the watershed outlet.

4. CONCLUSION

The accuracy of SWAT model in estimating hydrological characteristics in Ungagged Mamasa watershed is based on detail soil data from field study and sensitivity parameters which developed by the watershed characteristics. The estimate indicates that Mamasa watershed is in good condition.

Four soil and water conservation scenarios including bunch and mulch scenario, bunch terrace, mulch, and strip grass scenario, alley cropping and silt pilt scenario, and agroforestry scenario plus combination all scenario were developed and evaluated. The agroforestry scenario plus combination all scenario has the highest reduction of surface flow and sediment yield compared to other scenario. The alley cropping and silt pilt scenario have the second highest reduction of surface flow and sediment yield, followed by bunch terrace, mulch, and strip grass scenario, and bunch and mulch scenario. The combination scenario from all scenario showed that overall impacts is higher than individual scenario because each technique is interacted with other, so the accumulative result will be highest than individual scenario.

5. ACKNOWLEDGMENTS

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