Land use assessment of Jeneberang watershed using hydrology and water availability analysis

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Abstract. Jeneberang watershed management plays an important role to the function of Bili-Bili Dam as a multipurpose dam in maintaining year-round water availability (quantity and distribution), agricultural irrigation, water supply for the local freshwater provider (PDAM), demand on drinking water, and hydroelectric power plants in Gowa, Takalar, and Makassar. The study tried to answer the emerging problem of how to predict the hydrological state and water availability in the Jeneberang watershed throughout the year. This study applied the SWAT (Soil and Water Assessment Tool) model, a distributed model connected to the Geographic Information System (GIS) developed by Jeff Arnold for the USDA ARS (US Department of Agriculture - Agriculture Research Service). The hydrological model would be applied to evaluate a scenario of the climate change effects on the hydrology state. Understanding the watershed hydrological response to the changes in physics (land use) and climate (rainfall and air temperature) is an important component of water resource planning and management (Vorosmarty et al., 2000). One of the performance indicators for the watershed water balance is river discharge fluctuation (Surahman, 2016). The river regime coefficient demonstrates fluctuation in river discharge, a number showing the ratio between maximum discharge ($Q_{\text{max}}$) and minimum discharge ($Q_{\text{min}}$). SWAT model analysis showed the highest discharge ($Q_{\text{max}}$) of 30,805 m\textsuperscript{3}/sec and lowest discharge ($Q_{\text{min}}$) of 994 m\textsuperscript{3}/sec. The analysis employed the data of 2006 and 2009, resulted in the Nash-Sutcliffe (NS) Efficiency values of 0.65 (satisfied) and $R^2$ of 0.88 that in line with a study of Yusuf (2010) at the Cirasea watershed (0.74) and Junaidi (2011) at the Cisadane watershed (0.70). This value indicates that the SWAT method can predict the hydrological state of watersheds in Indonesia, including the Jeneberang watershed.

1. Introduction

Watershed plays a significant role in the catchment area for water availability in an area, so that it requires the best management plan. Water availability is the required water for production processes and daily needs that are generally generated from rainfall, lake, ground, and river. Watershed management aims to optimize the benefits of soil, water, and vegetation in alleviating drought, flooding, preventing soil erosion, increasing agricultural production, and increasing water availability.
in a sustainable manner [1]. Watersheds are functioned as a catchment area, water storage and water distribution [2]. SWAT model predicts the watershed scale, developed by Jeff Arnold for the USDA-ARS (US Department of Agriculture - Agriculture Research Service) in the early 1980s. It is a combination of several models developed by ARS (Agriculture Research Service) and is a further development of the SWRRB (Simulator for Water Resources in Rural Basins) model. Other models that play a role in the development of SWAT are CREAMS (Chemical, Runoff, and Erosion from Agriculture Management Systems), GLEAMS (Groundwater Loading Effects on Agriculture Management Systems) and EPIC (Erosion-Productivity Impact Calculator) [3]. SWAT model has been widely applied for simulation responses to the processes of water movement and environmental change to solve water and ecological problems. A number of studies have employed the SWAT model to evaluate the impact of agricultural water management practices on water resources. The SWAT model was developed for the hydrological simulation process at the basin scale [4]. The application of hydrological models and appropriate procedures for calibration and data validation are important for the research procedures [5]. SWAT is a comprehensive, semi-distribution basin model that requires several input parameters, a parameterization and calibration model. Several calibration techniques have been developed for SWAT, including manual calibration procedures and automatic procedures using several complex evolutionary methods and other general methods [6]. SWAT model can predict the long-term availability of water on the effects of land use and agricultural management [7]. The utilization of the SWAT model in Indonesia needs to be prior calibrated and validated in accordance with the availability of data, so it can reproduce data to be more accurate to the actual conditions. This process is important since each watershed has different characteristics. This analysis can be performed using the SWAT model which is a distributed model connected with Geographic Information Systems (GIS). The SWAT model is operated at daily time intervals and is designed to predict the long-term impact of land management practices on water resources, sediments and agrochemical yields on large and complex watersheds with different soil, land use and management scenarios [1]. SWAT model allows different physical processes to be simulated in a watershed.

2. Logical framework

![Figure 1. The logical framework of the study.](image-url)
3. Methods
The study took place in the Catchment area of Jeneberang Watershed, geographically located at 5° 16′26.89" S 119° 34 "48" E. Administratively, Jeneberang watershed includes in Gowa Regency, South Sulawesi Province, Indonesia. The equipment used was computer with the installed software (Microsoft Office 2010, ArcGIS 10.3, and Global Positioning System or GPS), topographical map, Reconnaissance Soil Map (1: 25,000); Digital Elevation Model or DEM map (30 meters resolution); Landsat imagery; data on land use characteristics, soil characteristics, slope, rainfall, temperature, humidity, solar radiation, soil physical properties, topography, land cover vegetation, and water debit. Data were entered into the data input file. The analysis was based on data obtained from the observation and data analysis using the Geographical Information System (GIS) integrated with the SWAT model. Information on land use was obtained from Landsat imagery.

3.1. Steps on GIS-based data
3.1.1. Map-Register. Imaginary map of the study was obtained; a date with a resolution of 30 meters. Furthermore, the map is equipped by laying out its graphic coordinates. There are two types of coordinate systems that apply internationally: 1. Geographical coordinate, the axis used is longitude (W and E) perpendicular to the equator and latitude (N and S) parallel to the equator. Geographical coordinate is expressed in degree, minute, and second. 2. UTM (Universal Transverse Mercator) or grid coordinate is expressed in meters, this coordinate states the position of a point in the measure of the distance of each reference point. Registration is done using the Arc GIS 10.3 program. Steps of SWAT model analysis using the Geographic Information System (GIS) software are; Delineation of the observed area. It is a process of delineating space to limit the zones of certain areas/regions so that it looks different from the zones of other areas/regions around it [8]. In watersheds based on Digital Elevation Model (DEM) data of the watershed area to be studied, it is carried out automatically by the SWAT model after the outlet point which is the observation point of discharge measurement is determined, which in this study the outlet point is the National River Flow Archive (NFRA) Station point belongs to the South Sulawesi Provincial Public Works Agency at Bili-Bili Dam. The DEM data used in this study is ASTER Global DEM V2 data with a resolution of 30 meters. The observation area will be delineated based on the natural topography of the watershed. The method used in the delineation process is the threshold method, where the threshold value used will determine the amount of river network formed. The result of this delineation is the formation of the outer boundary of the watershed which in the SWAT model is defined as a basin. Along with the formation of the basin, river networks and outlet points are also formed at each branching river.

3.1.2. Establishment of Hydrological Response Unit (HRU). After the delineation process, the HRU was formed. HRU is a hydrological analysis unit formed by following soil characteristics, slope class, and specific land use. At this stage, the collected data of DEM, land use data, slope class, and soil characteristic data that were formed automatically by the SWAT model overlay. The formation of HRU consists of slope intervals, land use raster maps and land raster maps of the UTM coordinate projection system format, and thresholds of the percentage total land use 10%, soil type by 5%, and 5% slope [9].

3.1.3. Combining HRU with climate data. The combining HRU and climate data processed were done after the analysis unit was formed. At this step, the simulation period was prior determined for the next to enter climate data. Climate data input was carried out to obtain the output in the form of a daily discharge simulation model.
3.1.4. Simulation. SWAT model simulation requires climate data (weather generator data) in the form of solar radiation, wind speed, temperature, rainfall, and dew point at the stations representing the watershed area. The simulation applied the SCS method Curve Number to predict the surface flow. The SWAT model was calibrated according to actual watershed data. The analysis was to compare the predicted discharge of the calibrated SWAT model and the water discharge measured from the water level data at the NFRA Station of Bili-Bili Dam, Jeneberang watershed. This model was furtherly employed to make predictions for certain types of scenarios.

4. Results and discussion

The Jeneberang watershed is located in the western part of the administrative area of Gowa Regency, South Sulawesi Province, Indonesia. Geographically, the Jeneberang watershed is located at 119°23'50"E - 119°56'10" E and 05°10'00"N- 05°26'00"S. The location elevation is between 600-2,833 masl. The Jeneberang watershed covers 385,088 km² or 38,508.75 Ha.

4.1. Climate

The highest average monthly rainfall occurred in January of 534.6 mm, while the lowest in September was 381 mm. Annual rainfall in the Jeneberang watershed varies greatly, during the period 2006 - 2015 the highest amount of rainfall occurred in 2015 amounted to 3,815 mm, while the lowest in 2006 was 534.6 mm. The maximum average temperature in the Jeneberang watershed ranges 24.80–28.60ºC, while the minimum average ranges 21.24–27.40ºC. Monthly average solar radiation in the Jeneberang watershed is 20.59 MJ/m²/day, while humidity is 86%.

4.2. SWAT model analysis using Geographical Information System (GIS) software

Delineation of watershed areas based on DEM (Digital Elevation Model) data of watershed areas is studied. The DEM data were obtained from 1: 25,000 topographic maps derived from ASTER Global DEM V2 data with a resolution of 30 meters by using Arc GIS 10.3 software. The study area was delineated based on the natural topography of the watershed. The study applied the threshold method, where the threshold value used determined the amount of river network formed. Delineation of watersheds was carried out with a threshold of 100 ha. It aimed to cover the entire river network in the Jeneberang watershed. The delineation resulted in the outer boundary of the watershed, which in the SWAT model is defined as the basin. Along with the formation of the basin, river networks and outlet points were also formed in every branching river (figure 2).

![Digital elevation model (DEM) Jeneberang watershed.](image-url)
Forms of Jeneberang watershed topographic are automatically set by SWAT in the DEM analysis. The forms are classified into 5 interval classes namely: 0-8% (flat), 8-15% (sloping), 15-25% (moderately steep), 25-40% (steep), and> 40% (very steep). Most of the Jeneberang watershed area is classified as steep (25-40%), covering 195,665 ha or 29.42% of the total Jeneberang watershed area. The very steep area (> 40%) is identified in the upper watershed area covering 215,837 ha or 32.45% (table 1). Determination of the slope class refers to the Director-General of RLPS, the Ministry of Forestry (2009).

| Slope class          | Covering area |
|----------------------|---------------|
|                      | Ha | %     |
| Flat (0-8)           | 5,408.10   | 14.04 |
| Sloping (8-15)       | 5,315.82   | 13.80 |
| Moderately steep (15-25) | 9,138.70   | 23.73 |
| Steep (25-45)        | 12,910.09  | 33.53 |
| Very steep (>45)     | 5,736.04   | 14.90 |
| Total                | 38,508.75  | 100.00|

The land use covering the area in each sub-watershed as a result of delineation is presented in table 2.

| Land use purpose            | Area (ha) | %     |
|-----------------------------|-----------|-------|
| Forest                      | 22,599.49 | 58.69 |
| Mixed dryland agriculture   | 2,419.25  | 6.28  |
| Open land                   | 1,170.46  | 3.04  |
| Settlement                  | 97.89     | 1.55  |
| Paddy field                 | 6.039     | 0.15  |
| Brushstrokes                | 3,127.93  | 8.12  |
| River                       | 2,544.96  | 6.61  |
| Waterbody                   | 9.36      | 0.02  |
| Total                       | 38,508.75 | 100.00|

The HRU formation automatically generated by the GIS program after putting the outlet point of debit measurement at the Bili-Bili Dam data spot. HRU is a hydrological analysis unit based on soil characteristics, slope class, and land use. This step was performed by overlaying the results of DEM (Digital Elevation Model) data, land use data, slope class, and soil characteristics data, which are generated automatically by the SWAT model. HRU formation consists of slope intervals, land use raster maps and land raster maps using coordinate system format of UTM (Universal Transverse Mercator) projection. The percentages of the threshold are 10% land use, 5% soil type, and 5% slope. The model produced 582 outputs and formed 19 sub-basins (figure 3).
The input data in the HRU analysis process consists of spatial data (land use maps, maps of soil types, and slope class maps) and numerical data. The land use map used is the Jeneberang watershed map in 2017. Reclassification results of the land use map obtained the type of soil and land use area. The soil map contains the distribution of soil types in the Jeneberang watershed. Soil numeric data is entered into the soil database in the Edit SWAT Input model. The slope class map is formed automatically based on the DEM map. The Multiple Slope method was chosen to obtain 5 slope classes and their extensive area. In general, there are contain four types of soil in the study area. The most extensive type of soil is Komp-Latosol (22,220.36 ha or 57.70%), then followed by Andosol (7,701.73 ha or 20.00%), Latosol (5,303.79 ha or 13.77%), and Mediterranean (3,282.88 or 8.53%). Geological formations in the Jeneberang watershed, according to Nuradin et al., (2014) [10], include young alluvium rocks originating from river sediments (6,074.45 ha or 15.76%), andesite basalt (18,412.80 ha or 47.76%), and tuffite rocks derived from mudrocks and sandstone (14,064.75 ha or 36.48%).

4.3. Calibration
Calibration was performed by comparing the daily discharge data from AWLR measurements in the field with the inflow model discharge data [10]. Calibration is needed to obtain a simulated river flow discharge close to the observation value [11]. Calibration is the process of selecting parameter combinations to increase the coherence between the observed/measured hydrological responses and the simulation results (Surahman, 2016). The calibration was to determine the relationship between the flow of river flow from the SWAT model and the measurement of river flow (observation). The step used river debit data from (period July 1 to November 31, 2006) using the manual calibration method (trial-and-error). There are three calibration methods, namely trial, and error, automatic and combination. In the trial and error method, the parameter values are manually matched by trial-and-error. This method is widely used and recommended for complex models. The combination method applies automatic calibration to determine the range of parameters, then a trial and error were performed to determine the optimal combination details [12].
Calibration values for the Jeneberang watershed were obtained using the manual calibration method (trial-and-error model). The parameter CN2 (SCS curve number) refers to the type of land use based on the hydrological group (Surahman, 2016).

The results obtained the Nash-Sutcliffe (NS) efficiency values (0.50; satisfactory) and $R^2$ (0.65) (Figures 5 and 6). The results are In line with a study by Yusuf (2010) [13] in the Ciracea watershed, resulting in the NSE calibration value (0.74) and Junaidi and Tarigan (2012) [14] in the Cisadane watershed, resulting in the NSE calibration value (0.70). Likewise, a study of Bagmati watershed Nepal, India, using the SWAT model. The NSEs obtained for resulted calibration and validation were 91.54 and 77.31%, respectively. Similarly, the $R^2$ is 0.917 and 0.93 (Manjan et al., 2014). This shows that the observed and predicted discharge closely matches the trend. So, there is a strong positive correlation between observed and predicted discharge. This value indicates that SWAT can also be applied to predict the watershed hydrological conditions in Indonesia. One of the performance indicators, especially the watershed of a watershed, can be seen from the fluctuation of river discharge in the watershed. Fluctuations in river discharge can be seen from the value of the river regime coefficient (RRC), which is a number indicating the ratio between maximum discharge ($Q_{max}$) and minimum discharge ($Q_{min}$). SWAT model resulted in the highest discharge ($Q_{max}$) 30,805 m$^3$/sec while the lowest discharge ($Q_{min}$) 994 m$^3$/sec. According to Regulation No. P61/Menhut-II/2014 about the
watershed management information system, the RRC of the Jeneberang Watershed in 2016 is still relatively high (26.650 m³/sec).

4.4. Validation
The application of adequate hydrological models and procedures for calibration and data validation is necessary [5]. Validation is the process of evaluating the model to get a picture of the level of uncertainty owned by a model in predicting hydrological conditions. Validation aims to prove that a method can provide consistent results [15]. The validation is done by comparing the observational daily debit data for July–November 2009 with the simulated daily debit data using calibration parameters. The consistency of the SWAT model after validation can be seen from the river discharge of the SWAT model with the measurement of the river discharge indicated by the Nash-Sutcliffe (NS) value of 0.55 (satisfactory) and $R^2$ of 0.58. The results of river flow validation in 2009 are presented in figure 6 and figure 7.

![Figure 6](image1.png)

**Figure 6.** Comparison of debits from the measurement and validation of the modeling on July–November 2009.

![Figure 7](image2.png)

**Figure 7.** Regression analysis of debit from the measurement and validation of the modeling on July–November 2009.

The land cover map of the Jeneberang watershed in 2010 (scale 1:100,000) demonstrates domination of mixed dryland agriculture (16,816.92 ha or 65.62%), followed by forest (6,768.89 ha or 26.41%), paddy fields (1,161.38 ha or 4.53%), brushstrokes (739.43 ha or 2.89%), grasslands (120.09 ha or 0.47%) and water bodies (21.39 ha or 3.11%). Mixed upland agriculture is a combination of dryland farming with woody plants on sloppy areas. Land management by making terraces has been
Land-use change in a watershed is a process of identifying differences in the existence of an object or phenomenon observed at different times in the watershed. Land use is generally influenced by two main factors namely natural factors (climate, topography, land or natural disasters) and human factors (in the form of human activity on a piece of land). Human factors seem more dominant than natural factors because most land-use changes are caused by human activities in meeting their demands on a specific plot of land [15].

Tree cover loss could serve serious implications for water resources since the interception decreases and the infiltration rate of the soil is exceeded when the shower moment. These changes have the potency to affect the faster flow and produce a changing flow regime [16]. Land use refers to human activities directly related to land, utilizing resources and disturbance to the ecological process that determines the function of land cover [17]. Based on the 2006 and 2015 land use maps published by the Directorate General of Forest Planning, the Jeneberang watershed has been changed. The change occurred in all land uses in the Jeneberang watershed. For the period of 2006 to 2015, increases in the area were identified on forests (1,226.53 ha), brushstrokes (6,360.43 ha), and paddy fields (1,161.38 ha). The decrease occurred in water bodies (19.74 ha), mixed dryland agriculture (150.20 ha), and grasslands (104.46 ha). The biggest increase in percentage occurred in brushstrokes (24.82%), while the biggest decrease occurred in mixed dryland agriculture (31.80%). From 2006 to 2015, the increase also experienced mixed dryland agriculture (7,852.45 ha) and water bodies (19.74 ha). The decline occurred in forests (597.14 ha), brushstrokes (6,422.11 ha), and rice fields (852.94 ha). In 2015, an increase of 629.22 ha of forests was recorded. This indicates that the presence of forests in the Jeneberang watershed is very important in the regulation and control of the water system which includes the quantity, quality and period of water supply. In line with a study by Sumarniasih (2015) [11] in the Ayung watershed of Bali, debit, as an output of the hydrological process, could be used as an indicator to assess the quality of land use of a watershed. The results of this study illustrate that rainfall, the driving factor of a high-fluctuating debit, is caused by changes in land use from upstream to downstream of the watershed, making the watershed ecosystem cannot be functioned properly. Rainfall could all become surface runoff because land cover changes. The crop cannot cover the surface of the ground tightly and permit the ground surface opened. Changes in the land use of the watershed area will affect the watershed hydrological conditions such as increased peak discharge, surface runoff coefficient, surface flow volume [18].

| Year | Precipitation (mm) | Number of flows | Base Flow (mm) | Direct Runoff (mm) | Runoff Coefficient |
|------|-------------------|----------------|--------------|-----------------|-------------------|
| 2006 | 3,053             | 2,499.7        | 18.48        | 268.82          | 0.82              |
| 2015 | 3,815             | 2,661.3        | 40.71        | 465.07          | 0.69              |

| Year  | Q Max (m³/sec) | Q Min (m³/sec) | RRC (Q Max/Q Min) |
|-------|----------------|----------------|-------------------|
| 2006  | 1,883.7        | 208.2          | 9,048             |
| 2015  | 2,254.2        | 238.5          | 9,452             |

Table 3. Hydrological status of Jeneberang watershed.

Table 4. The fluctuation on water debit of Jeneberang watershed.
Based on the precipitation in 2006 (3,053 mm), the runoff coefficient for the Jeneberang watershed is 0.82. This illustrates that 82% of the rainfall in the Jeneberang watershed will be a surface runoff. The increase in dryland agriculture in 2006-2015 affected the direct runoff value from 268.82 mm to become 465.07 mm. Meanwhile, the decrease in forests by 597.14 ha declined the base flow of 40.71 mm to be 9.46 mm. The effect of vegetated land use in overcoming surface runoff problems is shown by the amount of surface runoff in 2006 of 965.07 mm, lower than in 2015 of 268.82 mm. The effect of vegetated land use in increasing infiltration capacity is shown by the base flow in 2006 and 2015, respectively at 18.48 mm and 40.71 mm. Decreasing land use in the period 2006-2015, namely in mixed dryland agriculture and increasing brushstrokes and paddy fields resulted in an increase in runoff coefficient values from 0.82 to 0.69, and river regime coefficient from 9.048 m³/sec to 9.452 m³/sec. Conversion of land from the well-water absorbing into the lack-water absorbing causes an increase in the amount of rainfall becoming surface runoff.

5. Conclusion
This research concluded that;
1. Vegetated land use contributes to overcoming the decline in surface flow rates from 965.07 mm in 2006 to 268.82 mm in 2015. Vegetated land use can also elevate infiltration capacity, demonstrated by the base flow of 18.48 mm in 2006 to be 40.71 mm in 2015.
2. The SWAT model is a software used for predicting the hydrological state of Jeneberang watershed. The statistical test resulted in the Nash-Sutcliffe (NS) Efficiency value of 0.65 (satisfactory) and R²: 0.87. This value indicates that SWAT can predict the hydrological conditions of watersheds in Indonesia, including hydrological conditions based on changes in the land use of Jeneberang watershed.

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