Impact of land use change on groundwater flow using SWAT model, study case: Tanralili Sub Watershed

S Surahman¹, H Zubair², A Munir³ and M Achmad³

¹Agriculture Study Program, Hasanuddin University Makassar Graduate School 90245, South Sulawesi, Indonesia
²Department of Soil Science, Faculty of Agriculture, Moslem Maros University 90512, South Sulawesi Indonesia
³Department of Agricultural Technology, Faculty of Agriculture Hasanuddin University Makassar 90245, South Sulawesi Indonesia

E-mail: hazairinzubair@gmail.com

Abstract. Land-use changes impact the condition of the watershed ecosystem primarily in supporting the availability of water resources, which is currently a problem in meeting human needs. This study aims to identify the impact of land-use change on the bottom flow in the Tanralili sub-watershed. In SWAT model procedure are divided into several stages, namely: (1) watershed delineation; (2) forming HRU (3) Hydrology Response Unit (HRU) analysis; (4) climate data input; (5) building climate data; (6) run model; (7) calibration and validation and (8). simulation of hydrological parameters to determine the best land management. The result shows that the model has a good performance in predicting discharge flow with the NSE value in the calibration process of 0.23 (acceptable). In predicting the flow of discharge in the validation process, the NSE value is 0.62. The SWAT model can predict the impact of land-use changes on hydrological characteristics, especially the basal flow in the Tanralili sub-watershed. Analysis of the Tanralili Sub-watershed's hydrological characteristics, the SWAT results in 2010, 2015, and 2020 can be shown by the baseline flow of 494.64 mm 247.26 mm 256.48 mm, respectively.

1. Introduction

Land use/land cover change is a general trend in all parts of the world [1]. Information about the water cycle in ecological systems is crucial for water management in the catchment area in the face of global changes. At this scale, the impact of land use/land cover change affects the carbon and nitrogen cycle in the atmosphere, albedo, surface runoff, groundwater holding capacity, and biodiversity [2,3]. Land-use change affects the hydrological cycle on a regional and global scale [4]. Rainfall is a significant factor in supporting resources that play a role in global and socio-economic activities[5]. The amount of river flow is very much control by rainfall and groundwater flow, which significantly impacts flood control, hydropower, navigation, and ecological factors [6]. In 2000, the Tanralili watershed area showed that land cover conditions with a high vegetation density level between 81% and 100% were around 8,548 ha or approximately 33.28% of the total area of the Tanralili Sub-watershed. However, after 13 years, the high vegetation density level decreased to only 2,329 ha or 9.07%. The indicates that there has been a high loss of vegetation density of around 24.21% or 6,219
ha. The decrease in vegetation density is caused mainly by land-use changes, especially shrubs and forests, to mixed dryland agriculture [7,8].

The interactions that occur in nature, such as ecological, physical, and hydrological interactions, are not well understood concerning land-use changes currently occurring in the environment around us. Studies in agriculture are at the core of environmental change studies because they are located between ecosystems and communities[9]. Therefore, the basis for assessing investment decisions in agriculture, plantations, water resources management, calculation of the amount of water and carbon in the catchment area can be known from the water balance [10]. In water resource management, understanding groundwater and surface water interactions is very important and the protection of ecosystems that also depend on groundwater [11]. Water resource management can be managed using an integrated water resources management approach by strengthening coordination among stakeholders to manage and plan water resources in the watershed area [12].

Although this study is beneficial for water resources management, its impact on hydrological benefits has not been assessed. Therefore, in this study, hydro-climate modeling was conducted to see the impact of land-use changes on hydrological characteristics. Continuous model scenarios can help identify reasonable measures for assessing environmental ecological status [13]. The hydrological model has been widely used because it has been tested and documented (SWAT) [6]. This study examines the impact of land-use changes on the basement flow of the Tanralili watershed using the SWAT Model.

2. Materials And Methods

This research was conducted in Tanralili Sub-watershed (DAS Maros) South Sulawesi Province. It is geographically located between 5° 0’ to 5° 12’ LS and 119° 34’ to 119° 56’ East Longitude with an area of 25,627.59 ha (figure 1). in three main stages. The first stage is collecting secondary data. The second stage is collecting and analyzing soil samples for soil data input to the SWAT model. The third stage is to run the SWAT model, which is divided into several separate stages, namely: (1) watershed delineation; (2) analysis of the Hydrology Response Unit (HRU); (3) climate data input; (4) build climate data; (5) run model; (6) calibration and validation and (7) simulation of hydrological parameters.

Land-use changes were identified by overlaying the Land Use Map of the Tanralili Sub-watershed in 2010 with the 2015 Land Use Map. Besides, an overlay of the Land Use Map of the Tanralili Sub-watershed in 2015 and 2020 was obtained to obtain information on land-use changes both spatially and temporally. The process of analyzing land-use change is carried out using the ArcGIS 10.3 program.

Input data prepared at the data collection stage is entered into input data files (SWAT Input File). There are 17 input data files related to hydrological analysis. Precipitation (PCP), temperature (TMP), solar radiation (SLR), relative humidity (HMD), and soil (SOL) files were prepared by entering climate and soil data into each file's parameters. Meanwhile, all data about; configuration (FIG), file management (CIO), chemical oxygen demand (COD), basin (BSN), topographically-defined subbasin (SUB), hydrological response unit (HRU), management number (MGT), groundwater (GW), and routing input data file (RTF), are formed after the analysis procedure is carried out. Land cover and settlement data used that has been provided by SWAT in the CROP and URBAN files. Climatic data in the form of daily data including rainfall (mm), maximum and minimum temperature (°C), solar radiation (MJ / m² / day), wind speed, and air humidity (%) are prepared in PCP, TMP, SLR files. HMD and WGN. Preparation of climate data related to the method of calculating the evapotranspiration used [14].

The model needs more data due to insufficient factors taken into account during inputting data. Some significant factors include determining the curve number, previous groundwater content, and the correct hydrological group. It is also necessary to pay attention to the accuracy of the land use map used in the simulation and the DEM resolution used to delineate watershed boundaries.

Any analysis that uses modeling must be accompanied by testing to assess the accuracy of the model's outputs against the data from observations or field measurements. In this study, the hydrological process model's output or variable being tested is the flow rate (FLOW_OUT). The calibration period was chosen to determine which year will be used in the calibration and validation process. In this study, 2010
is used as the year of calibration and 2015 as validation. This period was chosen because of relevant data resulting in the best NSE and r² values among other years. The statistical method used to test the model is the Nash-Sutcliffe (NS) model efficiency equation:

\[ NS = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \]  

where \( y_i \) is the measured flowrate (mm), \( \hat{y}_i \) is the simulation result (mm), and the average measured flowrate. The NS model's efficiency is grouped into three classes (Table 1): good, satisfying, and unsatisfactory.  

**Table 1.** Classification of NS values.

| NS Value | Category               |
|----------|------------------------|
| \( NS \geq 0.75 \) | Good (very satisfying) |
| \( 0.75 > NS > 0.36 \) | Satisfactory           |
| \( NS < 0.36 \) | Less satisfactory       |

Source: Nash-Sutcliffe (1970).

Figure 1. Map of the Tanralili Sub-watershed [7].

3. Results and discussion

3.1. Analysis of hydrological characteristics using the SWAT model

3.1.1. Watershed delineator. Sub-watershed delineation in the SWAT model is carried out automatically through the DEM delineation process. The delineation process results in watershed boundaries, sub-watershed boundaries, and river networks. Watershed delineation is carried out with a threshold of 100 ha to cover the entire river network in the Tanralili Sub-watershed.  

Based on the delineation process of the Tanralili Sub-watershed, the main river network was formed, a watershed boundary with a total area of 27,838.90 ha and 23 sub-watersheds. The discharge observation outlet point is located in Sub-watershed number 6. The measurement discharge data from the Lekopancing outlet is used as primary data compared to simulated data discharge in the SWAT model.
3.1.2. **HRU analysis (Hydrology Response Unit)**. HRU is the smallest unit of analysis used in the calculation of the SWAT model. The Hydrology Response Unit (HRU) is formed from overlapping land use maps/data, soil characteristics, and slope classes [15].

Input data in the HRU analysis process consists of spatial data and numerical data. Spatial data consists of land use maps, soil type maps, and slope class maps. Numerical data is characteristic soil data, including soil physical properties data. The land use map used is the Tanralili Sub-watershed data in 2005. The land map contains the distribution of soil types in the Tanralili Sub-watershed. Soil numerical data is entered into the soil database in Edit SWAT Input mode. Slope class maps are generated automatically based on the DEM map. The Multiple Slope method was chosen to obtain five slope classes and their widths. HRU data were obtained from the overlap of the three input data [15].

**HRU definition** The method used is a threshold by a percentage of 10%. The threshold's determination is intended so that the polygon area less than 10% will be combined with the closest polygon. Exceptions can be made with land use which has an area of less than 10%. HRU analysis resulted in 127 HRUs spread across 21 sub-watersheds.

3.1.3. **Climate database (Weather Generator Data)**. The SWAT model climate database is based on the calculation of climate data from 2010 to 2019, which consists of rainfall data, temperature (temperature data), humidity (Relative Humidity Data), solar radiation (Solar Radiation Data), and wind speed (wind). Speed Data.

3.1.4. **Hydrological characteristics analysis**. Primary flow data is obtained from the process of running the SWAT model. Hydrological data is obtained based on rainfall data influenced by temperature, humidity, wind speed, and solar radiation on land use conditions in 2010, 2015, and 2020. Data on hydrological characteristics are also influenced by soil characteristics and topography of the Tanralili Sub-watershed.

3.2. **Model parameterization**

The parameters used in a model's calibration process can differ between watersheds because each watershed has varying characteristics. The simulation parameter values are adjusted to produce an output close to the adaptive value in the field. Parameters sensitive to discharge changes are CN2, ESCO, EPCO, GW_REVAP, GWQMN, and RCHRG_DP (Santhi et al. 2006). Jha et al. (2010) suggest that the parameters sensitive to discharge values are CN, SOL AWC, GW_DELAY, GW_Alfa, and SURLAG. The parameters used in the calibration process in the Tanralili sub-watershed are surface flow curve number (CN), baseline flow alpha-factor (ALPHA_BF), groundwater 'delay' time (GW_DELAY), a minimum height of bottom flow (GWQMN), deep water percolation fraction (RCHRG_DP), soil evaporation factor (ESCO), plant uptake factor (EPCO), Manning value for the mainline (CH_N2), hydraulic conductivity in the alluvium mainline (CH_K2), and surface flow lag coefficient (SURLAG). Simulations are carried out to determine the optimal value according to conditions in the field [15].

The surface flow curve number parameters, the soil evaporation factor, and the plant uptake factor are used in the model calibration because they influence surface runoff. The value of the curve number can predict the amount of surface runoff or infiltration due to rainfall. The soil evaporation factor is a parameter that determines the amount of water in the soil, which will affect the surface flow curve number and the infiltration process that occurs. The plant uptake factor influences surface runoff due to plant roots' ability to absorb water and affects transpiration to impact soil moisture.

The baseline flow alpha parameters, groundwater 'delay' time, a minimum height of bottom flow, and deep water percolation fraction are used because they affect underground water flow. Also, the Manning value parameters for the mainline, the hydraulic conductivity in the alluvium mainline, and the lag coefficient of surface flow are used in the calibration process because they affect the shape of the hydrograph.
3.3. Flow Discharge Calibration
Calibration is the process of selecting a combination of parameters to increase the coherence between the observed/measured hydrological response and the simulation results. Model calibration is carried out to determine the relationship between river water discharge from the SWAT model and river water discharge measured. The river water discharge data were used from January 1 to January 30, 2010. There are three calibration methods, namely trial and error, automatic, and combination. The combination method is carried out using automatic calibration to determine the parameter range. Then, trial and error are carried out to determine the optimal combination details.

The parameters used in a model's calibration process can differ between watersheds because each watershed has its varying characteristics. The simulation parameter values are adjusted to produce an output close to the adaptive value in the field. Parameters sensitive to discharge changes are CN2, ESCO, EPCO, GW_REVAP, GWQMN, and RCHRG_DP (Santhi et al. 2006). Jha et al. (2010) also stated that the parameters sensitive to the discharge value are CN, SOL AWC, GW_DELAY, GW_Alfa, and SURLAG. The parameters used in the calibration process in the Tanralili sub-watershed are surface flow curve number (CN), baseline flow alpha-factor (ALPHA_BF), groundwater 'delay' time (GW_DELAY), a minimum height of bottom flow (GWQMN), deep water percolation fraction (RCHRG_DP), soil evaporation factor (ESCO), plant uptake factor (EPCO), Manning value for the mainline (CH_N2), hydraulic conductivity in the alluvium mainline (CH_K2), and surface runoff lag coefficient (SURLAG). Simulations are carried out to determine the optimal value according to conditions in the field [16].

In finding the appropriate calibration value for the Tanralili sub-watershed, a combination method is used, namely by using the SWAT CUP model (automatic model) and manual calibration (trial and error) [17]. The SWAT CUP model is software that can help modelers to calibrate, validate and analyze uncertainties in the SWAT hydrological model. The initial and final values in the calibration process can be seen in table 2.

Table 2. Parameter values at the SWAT model calibration stage in the Tanralili Sub-watershed.

| No. | Parameter  | Initial Value | Final score | Range     |
|-----|------------|---------------|-------------|-----------|
| 1   | GW_DELAY  | 31            | 22          | 0 - 500   |
| 2   | CN2        | 35 - 98       | 66 - 91 *   | 35 - 98   |
| 3   | ALPHA_BF   | 0.048         | 0.8         | 0 - 1    |
| 4   | GWQMN      | 0             | 200         | 0 - 5000 |
| 5   | CH_N2      | 0.014         | 0.05 and 0.1 ** | -0.01 - 0.31 |
| 6   | CH_K2      | 0             | 100         | -0.01 - 5000 |
| 7   | RCH        | 0.05          | 0.74        | 0-1      |
| 8   | ESCO       | 0.75          | 0.55        | 0-1      |
| 9   | EPCO       | 0.85          | 0.70        | 0-1      |
| 10  | SLAG       | 4             | 7           | 1 - 24   |

Note: * Values differ based on land use.
** Values differ by sub-watershed.

Based on the tests’ results, the Nash-Sutcliffe (NS) efficiency value was 0.23 (unsatisfactory)/acceptable, as shown in figure 2.
3.4. Flow discharge validation
Validation is the process of evaluating a model to get an idea of the level of uncertainty a model has in predicting the hydrological process. The validation step aims to prove that a process/method can provide consistent results by the specified specifications. The validation process is carried out by comparing the observation discharge's daily data in January 2015 with the daily simulation discharge data using the calibration parameter.

After validation, the SWAT model's consistency after validation can be seen from the SWAT model river discharge with the measured river discharge indicated by the Nash-Sutcliffe (NS) value of 0.64 (satisfactory). The results of river discharge validation in 2008 are presented in figure 3.

3.5. Effect of changes in land use on hydrological aspects
Based on land use maps for 2005, 2008, and 2011 published by the Directorate General of Planning at the Ministry of Forestry, it shows land-use changes in the Tanralili Sub-watershed. These changes occur in all land uses in the Tanralili Sub-watershed, as presented in table 3.

![Figure 2. Comparison of the observed flow discharge and simulated flow discharge after calibration (January 2010).](image2)

![Figure 3. Comparison of observation flow discharge and simulation flow discharge after validation (January 2015).](image3)

From 2010-2015, there was an increase in dryland agriculture mixed with shrubs, shrubs, and water bodies of 126.95 ha, 5.97 ha, and 16.2 ha, respectively. The decrease occurred in secondary dryland
forest, industrial plantation forest, paddy fields of 5.97 ha, 126.81 ha, and 16.17 ha. The most significant increase occurred in the use of dryland mixed with shrubs of 0.46%, and the most significant decrease occurred in the use of industrial plantation forest land by 0.46%.

The 2015 to 2020 period saw an increase in secondary dryland forest, rice fields, bushes, and empty land, respectively 64.41301.83 ha, 103.67 ha, 76.86, and 23.18 ha. The decline occurred in dryland agriculture mixed with shrubs and savanna, respectively 466.28 ha and 103.67 ha. From 2010 to 2020, there was an increase in secondary dryland forest covering 58.45 ha. This indicates that the presence of forests in the Tanralili sub-watershed is significant in regulating and controlling water management, including the quantity, quality, and water supply timing [18].

Table 3. The extent of land-use change in Tanralili Sub-watershed in 2010, 2015 and 2020.

| Land Use                        | 2010 Large | 2015 Large | 2020 Large | 2010-2015 | 2015-2020 | 2010-2020 |
|--------------------------------|------------|------------|------------|-----------|-----------|-----------|
| Secondary dryland forest       | 3,933.35   | 3,927.39   | 3,991.80   | -5.97     | 0.23      | 58.45     |
| Industrial plantation forest (HTI) | 1,855.49   | 1,728.68   | 1,728.68   | 6.21      | -0.46     | 0.00      |
| Dryland agriculture mixed with shrubs | 19,360.43 | 19,487.39 | 19,021.11 | 68.33     | 0.46      | 466.28    |
| Savanna                        | 223.09     | 223.09     | 119.42     | 0.43      | 0.00      | 103.67    |
| Rice fields                    | 1,692.34   | 1,676.17   | 1,978.01   | 7.11      | -16.17    | 301.83    |
| Shrubs                         | 717.76     | 723.73     | 827.40     | 2.97      | 0.02      | 103.67    |
| Waterbody                      | 56.43      | 72.46      | 149.32     | 0.54      | 16.02     | 76.86     |
| Open land                      | 0.00       | 0.00       | 0.00       | 0.08      | 0.00      | 23.18     |
| Total area                     | 27,838.90  | 27,838.90  | 27,838.90  | 100.00    | 100.00    | 100.00    |

Table 4. Effect of land-use changes on the baseline flow of the Tanralili Sub-watershed from the results of 2010, 2015, and 2020 SWAT analysis.

| Land Use | Rainfall | Basic Flow (GW_Q) |
|----------|----------|-------------------|
| 2010     | 4141.17  | 494.64            |
| 2015     | 2147.28  | 247.26            |
| 2020     | 3246.90  | 256.48            |

Figure 4. Groundwater flow (mm) in 2020, 2015, and 2020 land use.
Changes in land use in the 2010-2020 period tend to decrease the base flow value. Reduction of secondary dryland forest and dryland agriculture mixed with shrubs resulted in rainfall falling in the Tanralili Sub-watershed. Conversion of land from uses that can absorb water properly into the soil to uses causes the loss of the soil's ability to absorb water increases the rainfall amount that is surface runoff [19]. Based on the rainfall that fell in the Tanralili sub-watershed in 2011, which was 3,252 mm, the runoff coefficient for the Tanralili sub-watershed was 0.28. This illustrates that 28% of the rainfall that falls in the Tanralili Sub-watershed will become surface runoff.

4. Conclusions
The SWAT model can be used to identify Groundwater flows with an NSE value of 0.62. Changes in land use resulted in decreased base flow value for 2010 - 2020 by 494.64 mm and 256.48 mm, respectively. This research implies an effect of land-use change on hydrological characteristics in the Tanralili Sub Watershed.

Acknowledgments
The author would like to thank the Education Fund Management Institution (LPDP) the Ministry Finance Republic of Indonesia for its financial research support.

References
[1] Chemura A, Rwasoka D, Mutanga O, Dube T and Mushore T 2020 The impact of land-use/land cover changes on water balance of the heterogeneous Buzi sub-catchment, Zimbabwe Remote Sens. Appl. Soc. Environ. 18 100292
[2] Devaraju N, de Noblet-Ducoudré N, Quesada B and Bala G 2018 Quantifying the relative importance of direct and indirect biophysical effects of deforestation on surface temperature and teleconnections J. Clim. 31 (10) 3811–3829
[3] Winckler J et al. 2018 Different response of surface temperature and air temperature to deforestation in climate models Differ. response Surf. Temp. air Temp. to deforestation Clim. Model October 1–17
[4] Rockström J et al. 2009 A safe operation space for humanity Nature 461 472–475
[5] Tuffour-Mills D, Antwi-Agyei P and Addo-Fordjourn P 2020 Trends and drivers of land cover changes in a tropical urban forest in Ghana Trees, For. People 2 100040
[6] Shope C L et al. 2014 Using the SWAT model to improve process descriptions and define hydrologic partitioning in South Korea Hydrol. Earth Syst. Sci. 18 (2) 539–557
[7] Hasnawir, Kubota T, Sanchez-Castillo L and A. S. Soma A S 2017 The influence of land use and rainfall on shallow landslides in tanralili sub-watershed, Indonesia J. Fac. Agric. Kyushu Univ. 62 (1) 171–176
[8] Surahman S 2017 Impact of Land Use Changes on The Characteristics of Hydrology in Tanralili Sub Watershed of South Sulawesi Province Using SWAT Model J. Chem. Inf. Model. 8 (9) 1–58
[9] Brunke M and Gonsler T 1997 The ecological significance of exchange processes between rivers and groundwater Freshw. Biol. 37 (1) 1–33
[10] Ignace D D, Huxman T E, Weltzin J F and Williams D G 2007 Leaf gas exchange and water status responses of a native and non-native grass to precipitation across contrasting soil surfaces in the Sonoran Desert Oecologia 152 (3) 401–413
[11] Boulton A J, Findlay S, Marmonier P, Stanley E H and Maurice Valett H 1998 The functional significance of the hyporheic zone in streams and rivers,” Annu. Rev. Ecol. Syst. 29 59–81
[12] Zhang Y et al. 2016 Estimation of submarine groundwater discharge and associated nutrient fluxes in eastern Laizhou Bay, China using 222Rn J. Hydrol. 533 103–113
[13] Lam Q D, Schmalz B and Fohrer N 2012 Assessing the spatial and temporal variations of water quality in lowland areas, Northern Germany J. Hydrol. 438–439 137–147
[14] Yang J, Reichert P, Abbaspour K C, Xia J and Yang H 2008 Comparing uncertainty analysis techniques for a SWAT application to the Chaohe Basin in China J. Hydrol. 358 1–23
[15] Stehr A, Debels P, Romero F and Alcayaga H 2008, “Hydrological modelling with SWAT under conditions of limited data availability: Evaluation of results from a Chilean case study,” Hydrol. Sci. J., vol. 53, no. 3, pp. 588–601, 2008.
[16] Xu Y D, Fu B J, He C S and Gao G Y 2012 Watershed discretization based on multiple factors and its application in the Chinese Loess Plateau,” Hydrol. Earth Syst. Sci. 16 (1) 59–68
[17] Khakbaz B, Imam B, Hsu K and Sorooshian S 2012 From lumped to distributed via semi-distributed: Calibration strategies for semi-distributed hydrologic models,” J. Hydrol. 418–419 61–77
[18] Zubair H, D.A. Suriarimahardja D A, Massinai M A, Assegaf H, Lias S A, Solle M S & Ahmad A, Azikin B, Paharuddin, Anas A V, Arif S, Nurkin B, Sakka 2018 Das jeneberang 1 Makassar: Unhas Press
[19] Munir A and Faridah S N U R 2010 Fuzzy multi attribute decision making for river basin management 5 2301–2308