Surface water – Groundwater Coupled Modelling for Watershed Water Resources Sustainability Assessment

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Abstract. There are limited studies in Cisangkuy Watershed which shows the water resources availability and variability with respect to changing climates and land use. Uncertainties due to climate change and population growth have created a critical water resources situation for Cisangkuy Watershed. These uncertainties come from undescribed quantification of surface water – groundwater interaction. Investigating spatio-temporal variability of recharge-discharge is a critical initial step for water-resource management. The main objective of this study is to set up a physically-based spatially distributed SWAT and MODFLOW for the analysis of the different hydrological and hydrogeological component. The objectives to be achieved include 1) identifying the characteristics and distribution of river stream recharge-discharge 2) assessing surface water and groundwater quantity. The result shows that calibrated SWAT-MODFLOW model can represent surface water – groundwater interaction in Cisangkuy Watershed spatio-temporally. Baseflow from aquifer discharge is main factor that give contribution to river discharge in study area, so we can conclude that Cisangkuy Watershed has a good potential of water resources on the low area, but also has high potential of disaster due to groundwater like flood and landslide. This study is expected to develop water resources management in Indonesia. So that water resources sustainability can be analyzed from the aspect of the quantity of surface water and groundwater.

1. Introduction
Integrated groundwater and surface water simulation is important for water resources management, with the integration we can know the impact of various surface conditions on surface runoff and groundwater discharge, as well as when changes in groundwater conditions happen what impacts will occur at the river discharge. With a variety of natural and anthropogenic factors that affect the hydrological system of the Cisangkuy Watershed, a simulation model of groundwater-surface water integration is needed to understand its characteristics and provide an overview of recharge and discharges patterns within a space and time framework. In this case the simulation ability of groundwater and surface water will be evaluated in providing an overview of hydrological and hydrogeological conditions.

Based on the Geological Map of Garut - Pameungpeuk Sheet [1] and field observations, most of the aquifer lithology in the Cisangkuy watershed is volcanic rock produced by the eruption of the surrounding volcanoes in the direction of distribution following a lower topography. This aquifer is equated with the Cibeureum Formation based on the similarity of its physical [2]. Regionally the research area is composed of the Cibeureum Formation as the main aquifer and the Kosambi Formation as the aquitard. The Cibeureum Formation consists of repeating breccias with tuff, with a low level of consolidation and some basalt lava insertions, and has a Late Pleistocene - Holocene age.
Breccias in this formation are volcanic breccias composed by scoria fragments of igneous basaltic rocks and pumice [3].

2. Methods

2.1 Swat-modflow

Swat-modflow simulates water balance as a result of the integrating of SWAT and MODFLOW. SWAT covers surface hydrological processes such as rainfall, temperature, river flow, runoff, water content in the soil, actual evapotranspiration, and infiltration. On the other hand MODFLOW can reach groundwater processes in the saturated zone and groundwater discharge to the surface (Fig. 1). SWAT-MODFLOW works by replacing groundwater processes in SWAT with MODFLOW which is able to provide a more dynamic and temporally detailed picture of groundwater ([4][5][6]) Integration of MODFLOW with SWAT is done on 3 variables: deep percolation (water leaving the root zone is considered as infiltration), river water level from SWAT to MODFLOW, and baseflow (groundwater discharge) from MODFLOW to SWAT. The most important stage of the merging model is shown by the flow chart in Fig. 2 and explained as follows: because SWAT simulates surface water processes on the HRU scale and MODFLOW on a grid cell scale, in order to connect between the two HRUs need to be divided into grids that are has a coordinate called DHRU, this DHRU is intercepted with the MODFLOW grid for air flux exchange between SWAT and MODFLOW (Fig. 3)

Figure 1. Conceptual model of SWAT-MODFLOW [3]

Figure 2. Integration scheme of SWAT-MODFLOW [3]
3. Data

3.1 Input SWAT data
ArcSWAT 2012 was used to build a SWAT model of the study area because of its ability to visualize the results in ArcMap. Digital Elevation Model (DEM) 30 m resolution imported and used to delineate the watershed into 103 subbasins. The model calculates the direction and accumulation of surface and ground water based on the slope, river network, outlet points that have been determined at the Cisangkuy - Kamasan river monitoring point, Land use map 2011 (Fig. 4), and soil types 2005-2006 (Fig. 5).

After entering the data on soil type and land use, the next step is to categorize the slope level, the slope class is classified into 5 classes, namely flat (0-8%), ramps (8-15%), rather steep (15-25%), steep (25-40%) and very steep (> 40%) (Fig. 6). Calculation results in each HRU are added up to each subbasins. For use in general, threshold land use (20%), Soil threshold (10%), and slope threshold (20%). The final stage of the construction of the SWAT model is the inclusion of climatological data in the model which includes rainfall, temperature, relative humidity, wind speed, and solar radiation for the years 2002 to 2013 (12 years). Rainfall data is taken from observational data at the Cileunca observation point.
3.2 Input modflow data

Figure 4. Landuse map of Cisangkuy Watershed

Figure 5. Soil map of Cisangkuy Watershed

Figure 6. Slope map of Cisangkuy Watershed
The integrating of SWAT and MODFLOW is done through [7]. QSWATMOD creates a linking file between the DHRU SWAT grid and the MODFLOW grid so that data transfer can be performed for calculations. The next stage is the development of the MODFLOW model which includes DEM data for the study site with a resolution of 30 m, aquifer thickness of 100 m, Hydraulic conductivity $4 \times 10^{-5}$ m/sec, Specific Storage: $4 \times 10^{-5}$ / m (dense sand), Specific Yield: 0.21 (tuff) [8], K of River Bed material is $4 \times 10^{-5}$ m/sec, and initial groundwater depth is 3.5 m based on observations of average water table depth near the river in the study area. After all data have been entered, the settings for the simulation to be carried out. Like the length of time the simulation and the desired output. It should be noted that the quality of the results of the SWAT-MODFLOW greatly depends on the quality of the input of each SWAT and MODFLOW models.

4. Result and discussion

4.1 River stream discharge

The SWAT model of the Cisangkuy watershed model was calibrated to 2005 - 2009 of river discharge at the Cisangkuy - Kamasan observation point on an average monthly basis with SWAT-CUP [9]. For optimal simulation, a warm-up period of three years is needed so that the total data used is 8 years from 2002 to 2009 for calibration. Based on research conducted by [10] The parameters taken for study area were 14 calibrated parameters (Table. 1). SWAT simulation results and SWAT calibrated result are shown on a monthly basis, conducted for 2010 and 2012 compared to the value of water discharges at the Cisangkuy - Kamasan monitoring points. Fig. 7 shows the calibrated model discharge values have $R^2 = 0.67$, while the value initial simulation discharge value of $R^2 = 0.52$. The simulation results in Fig. 8 show the SWAT-MODFLOW simulation discharge has a more dynamic fluctuation pattern than the SWAT simulation itself, this shows that the SWAT-MODFLOW simulation has included the contribution factors of recharge and aquifer discharge in the simulated river discharge [11].

| Parameter Name            | Min Value | Max Value | Fitted Value |
|---------------------------|-----------|-----------|--------------|
| 1:R__CN2.mgt              | -0.5      | 0.5       | -0.49        |
| 2:V__ALPHA_BF.gw          | 0.0       | 1.0       | 0.89         |
| 3:V__GW_DELAY.gw          | 0.0       | 450.0     | 76.50        |
| 4:V__GWQMN.gw             | 0.0       | 5,000.0   | 1,750.00     |
| 5:V__CH_K2.rte            | 0.0       | 500.0     | 265.00       |
| 6:V__CH_N2.rte            | 0.0       | 1.0       | 0.97         |
| 7:V__ESCO.hru             | 0.0       | 1.0       | 0.71         |
| 8:V__EPCO.hru             | 0.0       | 1.0       | 0.39         |
| 9:V__REVAPMN.gw           | 0.0       | 500.0     | 395.00       |
| 10:V__SURLAG.bsn          | 0.0       | 20.0      | 5.40         |
| 11:R__GW_REVAP.gw         | 0.0       | 0.2       | 0.09         |
| 12:V__RCHRG_DP.gw         | 0.0       | 1.0       | 0.95         |
| 13:V__SLSUBBSN.hru        | 0.0       | 150.0     | 64.50        |
| 14:V__SHALLST_N.gw        | 1,000.0   | 2,000.0   | 1,890.00     |
4.2 River recharge – discharge interaction

To analyze surface water – groundwater interaction, an overlay map is presented from the recharge – discharge river segment map, marked with green for the positive flux value (recharge) and purple for the negative flux value (discharge). With the water table depth map marked with a negative value (yellow - orange) means the deep water table (recharge zone) and the positive value (blue) means the shallow water table (discharge zone). From the simulation results it can be seen that in general the river segments in the study area are dominated by discharges from aquifers to rivers and have shallow water table. From the simulation we can see the difference in flux in the rainy season and in the dry season. The Cisangkuy River segments in July (the Dry Season) have more recharge zones, this is because in the dry season more river segments are adjacent to the zone where the water table is deep in (Fig. 9), while in December (Rainy Season) segments of the Cisangkuy River experienced less recharge due to fewer areas that had deep water table (Fig. 10). Groundwater level is a major factor in determining recharge and discharge areas in a SWAT-MODFLOW simulation.
4.3 Water Balance

From the SWAT-MODFLOW water balance, it can be seen that the relationship between rainfall, surface and subsurface components have been coherent, when rainfall is high runoff, lateral flow, and absorption are also high. From the water balance, it can be seen that the base flow contributes the most to the river flow in the study area and has stable fluctuation over seasons, this indicates that water resources in the study area will not really affected by season. So it can be said that the water resources sustainability of the Cisangkuy Watershed is good enough. The following is a summary of water balance in the study area showed in Table.2. With the description of the variable as follows prec = rainfall in the watershed, surq = surface runoff to streams, latq = lateral flow to streams, gwq = groundwater flow to streams.

| Month | prec  | surq | latq | gwq  |
|-------|-------|------|------|------|
| Jan   | 309.5 | 5.1  | 53.4 | 136.7|
| Feb   | 297.5 | 5.5  | 59.6 | 142.8|
| Mar   | 258.5 | 1.8  | 48.3 | 147.5|
| Apr   | 234.5 | 3.0  | 41.9 | 138.2|
| Mei   | 129.3 | 0.4  | 21.3 | 121.9|
| June  | 67.3  | 0.2  | 10.4 | 101.0|
| Jule  | 29.5  | 0.1  | 1.0  | 86.3 |
| Agu   | 48.3  | 0.1  | 5.7  | 78.1 |
| Sept  | 127.0 | 0.4  | 19.7 | 80.2 |
| Oct   | 166.5 | 0.5  | 25.1 | 84.8 |
| Nov   | 316.8 | 5.0  | 57.1 | 105.0|
| Des   | 296.0 | 1.2  | 56.7 | 128.0|
| Sum   | 2280.5| 23.1 | 400.1| 1350.8|
5. Conclusions
SWAT-MODFLOW can show the impact of land use, morphology, and climatology on the recharge and discharge values in the study area spatio-temporally. While the recharge occurring in river segments is mainly influenced by the relative height of the surface with ground water level, the area where the ground water level is higher than the river segment is experiencing discharge. River flow in study area mostly affected by aquifer discharge so it has a good water resources sustainability. SWAT-MODFLOW can simulate the hydrological-hydrogeological process in a watershed for future plan and risk management of water resources in a variety of anthropogenic and climate change conditions.

6 References
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