Water Recharge Variability Across Serayu Watershed Using Soil Water Assessment Tool (SWAT)

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Abstract. Climate change and land use have an influence on the process of groundwater replenishment. Serayu watershed is categorized as one of the critical watersheds in Indonesia due to groundwater conditions. One that affects groundwater is the ability to replenish groundwater. The purpose of the study was to predict groundwater replenishment in the Serayu watershed. The hydrological model approach (SWAT/Soil Water Assessment Tool) was applied. Spatial data is used in SWAT model analysis, namely: Elevation data, stream, soil types, land use land cover, and climate data. Data analysis using QGIS 3.18 and QSWATPlus tools. The model calibration uses cn^2 values while NSE and R2 values are used to evaluate the model. Based on cn^2 values, SWAT models show performance that can be used for model implementation. Model validation between before and after the calibration process is (R2) 0.86 while the NSE value is 0.66. When viewed from the water equilibrium ratio, the average water recharge value in the Serayu watershed is 49.5 mm.yr^{-1} from the total precipitation of 2473.6 mm.yr-1. The largest hydrological component occurs in evapotranspiration and surface runoff (1879.9 and 549.2 mm.yr^{-1}, respectively). The high value of surface runoff indicates that the Serayu watershed needs attention regarding the ability of the land in the water recharge process
Keywords: groundwater, heterogeneity, SWAT, water recharge, watershed.

1. Introduction

Several watersheds (DAS) in Indonesia experience critical conditions due to damage that occurs from year to year. Watersheds in Indonesia, which have critical conditions and need to be revitalized, continue to increase in number to reach 108 watersheds [1–3]. Watershed damage in Indonesia is caused by changes in land use. The conversion of part of the forest area into a plantation is one form of land use change that causes an increase in the runoff and erosion coefficient in the area [4]. The increase in runoff and erosion coefficients can disrupt the availability of water resources, one of which is water contained in the soil or groundwater.

The Serayu watershed is one of the few watersheds in Indonesia that is experiencing critical condition. Based on data available in, Based on data from the Java Ecoregion Development Control Center (P3E), the Environmental Quality Index (IKLH) of the Serayu Watershed is 58.01 or medium category with a population density of 9.83 people/ha. The criticality status of water resources is close to critical or with a figure of 56.80 with security of 81.40% [5]. The critical condition is caused by many agricultural practices that do not heed the rules of conversion, so that the ratio of maximum discharge and minimum discharge of rivers is very high, and sedimentation exceeds the erosion rate threshold [6]. The condition of the Serayu watershed has heterogeneity between sub-watersheds, such as in the upstream eastern and western [7]. The upstream area of the eastern watershed of Mount Slamet is dominated by intensive agriculture while the southern upstream is still maintained as a protected forest area. The difference in land use land cover affects the process of filling groundwater

[8, 9]. Therefore, it is necessary to conduct thorough research on the Serayu watershed hydrological area related to the potential for water recharge which affects the availability of groundwater resources of the Serayu watershed.

Determination of the distribution of water recharge in one hydrological area can be done by various methods, such as: Linear regression, Multi-layer perception network, deep learning, and the use of spatial data [10-13]. In the study, one model that has been widely used will be used, namely the Soil Water Assessment Tool (SWAT) because the model is able to predict and simulate various hydrological processes in one watershed scale area [11, 14, 15]. The purpose of the study was to obtain the distribution of Serayu watershed water recharge using the SWAT model. This value is a reference in determining the potential distribution of groundwater.

2. Materials and method

2.1. *Study site*

The research was conducted in the Serayu watershed located in southern Java. Geographically, Serayu watershed is located at coordinates 07°05'-07°4' S and 108°56'-110°05' E (Figure 1). Serayu watershed is a watershed with a medium area, which is 371,581 ha. Serayu watershed is divided into nine sub-watersheds, namely: Begaluh, Serayu Hulu, Tulis, Merawu, Klawing, Sapi, Logawa, Tajum, and Serayu Hilir [16]. Serayu River is the main river, while the river. The soil types in the Serayu watershed consist of: latosol, regosol, lithosol, andosol, and podzolic [17]. The maximum daily rainfall in Serayu watershed ranges from 60-280 mm.d^{-1}
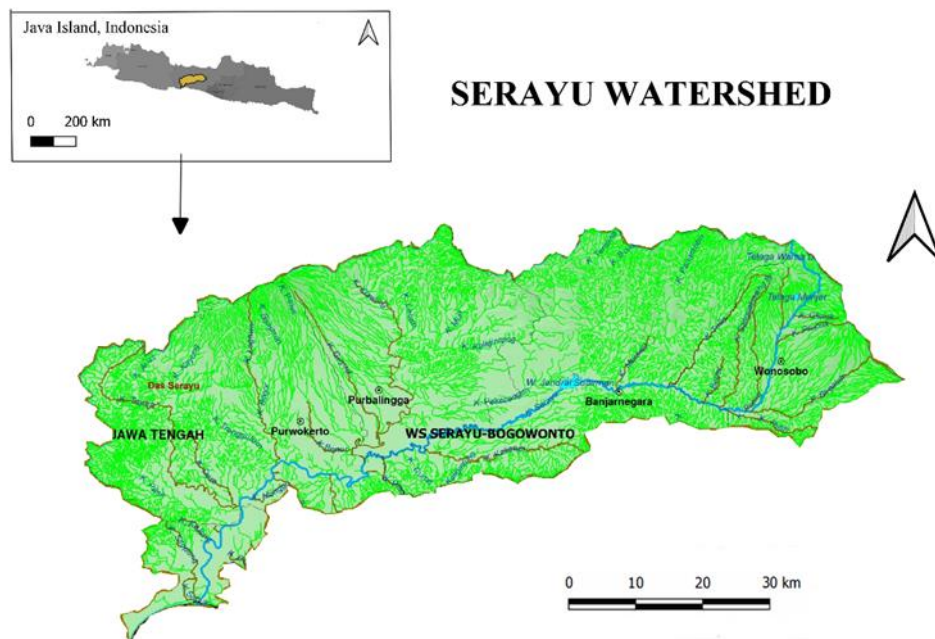

Figure 1. *Study region of Serayu watershed*

The study used secondary data in the form of Serayu watershed maps (BBWS Serayu Opak), Serayu watershed DEM maps (Indonesia Geospatial Portal), river maps (Ina Geospatial Portal), soil type maps (FAO Maps Catalog), land use maps (ESRI), and climate data (Nasa Power). Spatial data was processed using QGIS 3.18, QSWATPlus tools, and Ms. Excel. Model performance was validated using statistical criteria, namely R² and NSE values. The determination of the validation parameters refers to the research of Setiawan et al. [18] which states that the assessment of a model can be determined from the values of the R² and NSE coefficients. The R² value is the coefficient of determination of the observational water recharge data with prediction, while the NSE value is analyzed using the equation:

$$NSE = 1 - \left(\frac{\sum_1^n (X_i - Y)^2}{\sum_1^n (X_i - \overline{Y}_i)^2} \right)$$

Range of NSE value is from -1 to 1, when NSE will be acceptable if the value between 0 and 1.

2.2. SWAT

Quantum Geographic Information System (QGIS) version 3.18 is used for data analysis using SWAT models. The model input data consists of: Elevation, soil type, stream, and LULC (Figure 2).
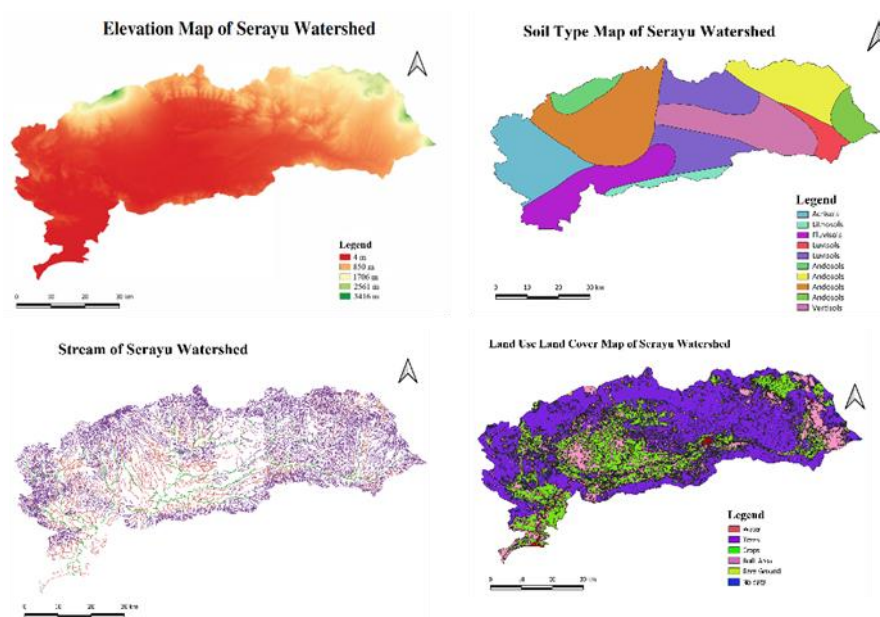

Figure 2. Thematic spatial map for SWAT model input.

2.3.1. Watershed delineation and Hydrologic Response Units (HRUs)

The first process in SWAT is the delineate stream of the watershed. The process will then divide the watershed into sub-basins according to the flow pattern. Therefore, at the initial stage, 2 data inputs are needed in the form of a Serayu watershed DEM map and a Serayu watershed river map. The result of the delination process divided the Serayu watershed into 178 sub basins (Figure 3a). The next process is the creation of HRUs maps formed by several input data, namely LULC and soil type. (Figure 3b).
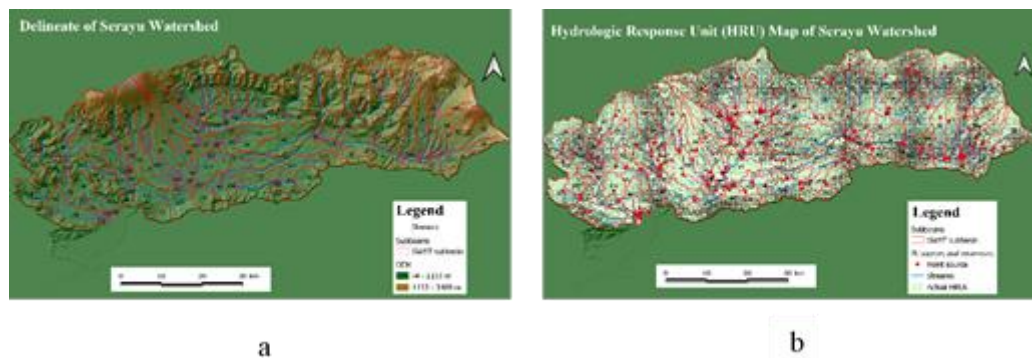
Figure 3. Delineated map of topographical Serayu watershed (a) and Hidrolic Response Units map (b) that consist of 178 sub basins.

2.3.2. Climate
Climate data used in this study consisted of precipitation, relative humidity, temperature, wind speed, irradiation. Climate data comes from 3 stations in the Serayu watershed and is adjusted to the rain station data attached to the web with data belonging to BBWS (Balai Besar Wilayah Sungai) Serayu Opak Bogowonto.

2.4. SWAT Model Simulations
QGIS 3.18 requires the QSWATPlus plugin to perform data analysis. Data input is in the form of climate data and HRUs. The selected simulation output is water recharge. The SWAT modeling process then has calibration with sensitive parameters (cn^2). Before the model is used to predict, a validation process is needed with reference using R^2 and NSE values.

3. Results and Discussion
3.1. Model performance
The SWAT analysis process yielded 178 sub basins. Using cn^2 1.5 resulted in a change mainly in the surface runoff value from 396.5 mm.yr^{-1} to 549.2 mm.yr^{-1}. The calibration also decreased the percolation value by about 50%, while the deep water recharge value was relatively fixed (Table 2). While the validation results, the value of the coefficient of determination (R^2) of 0.86 shows that the model is feasible for use in the Serayu watershed even though the NSE value of around 0.66 (satisfactory) can still be suitable for use [19]. The difference in the value of the sensitive coefficient can be caused by many factors, including the input data used is too large a variation of [20, 21]. Referring to the value of R^2, it can be seen that the value of the model with observation is not too different [22].

Tabel 1. Nilai water balance ratios

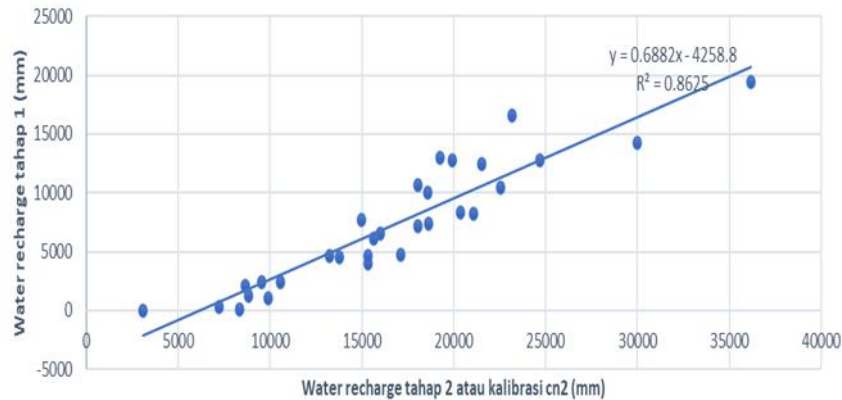| Water Balance Ratios	Before calibration (mm.yr^{-1})	After calibration (mm.yr^{-1})
Streamflow	445,3	568,9
Total Flow	455,7	560,5
Precipitation	2473,6	2473,6
Surface Runoff	396,5	549,2
Baseflow	59,2	11,2
Percolation	98,9	49,5
Deep Recharge	24,7	24,7
ET	1954,1	1879,9

Figure 4. Koefisien determinasi (R^2) water recharge of Serayu watershed

3.2. Water recharge and implication on ground water potential

The results of SWAT analysis in one water balance relationship show that most of the rainwater (2,473 mm) is transformed into evapotranspiration (1,875 mm). While the largest land process is surface runoff (549.24 mm). The amount of percolation is only 39.53 mm, part of which becomes base flow (10.12 mm) and partly becomes water recharge to the deep aquifer of 18.18 mm (Figure 5). Pöschke et al. [23] also found that the magnitude of seepage flow in the percolation process is no greater than the amount of water filling the deep aquifer. Climatic conditions also affect the amount of water recharge, as observed by Wendland, Gomes, & Troeger [24] in the same location measurement in the Ribeirão da Onça Basin there is a large difference in water recharge values between 14% to 38%. Meanwhile, soil and land cover factors also have a significant influence between the magnitude of runoff followed by a decrease in deep water recharge [25], although in some models it is found that soil characteristics and LULC only contribute slightly to changes in water recharge of a hydrological area [26].
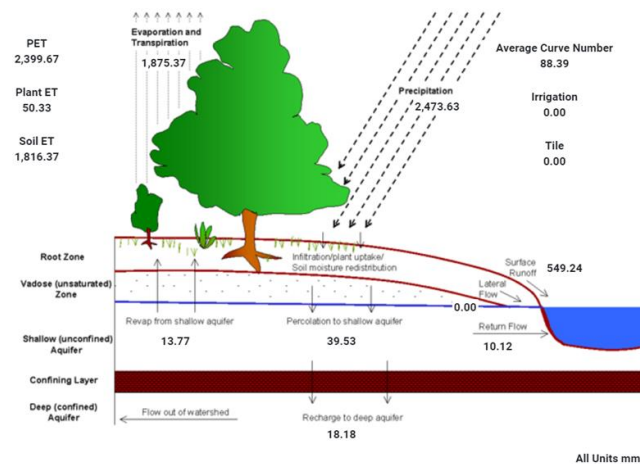

Figure 5. Water balance diagram of SWAT modelling result

When scaled up in the distribution of one Serayu watershed, it can be seen that the amount of water recharge does not depend on the location of the altitude of the place but more on LULC and Soil characteristics. The area south of Mount Slamet which is dominated by forests has a high groundwater replenishment ability (1,787-2,254 mm). Likewise, in the eastern upper Serayu watershed area, indicating high water recharge (Figure 6). While the northern upper Serayu watershed area, which is an area dominated by highland agriculture, has a low water recharge ability (120-930 mm). The low value of water recharge in agricultural cultivation areas is possible because rainwater mostly becomes surface flow. In agricultural land, soil conditions are saturated so that the soil has a low infitration

ability so that some of the water is converted into runoff [27, 28]. Meanwhile, in forest areas, it has vegetation cover that can increase the ability of the soil to infiltrate and be stored continuously into ground water through the process of deep water recharge [29, 30].
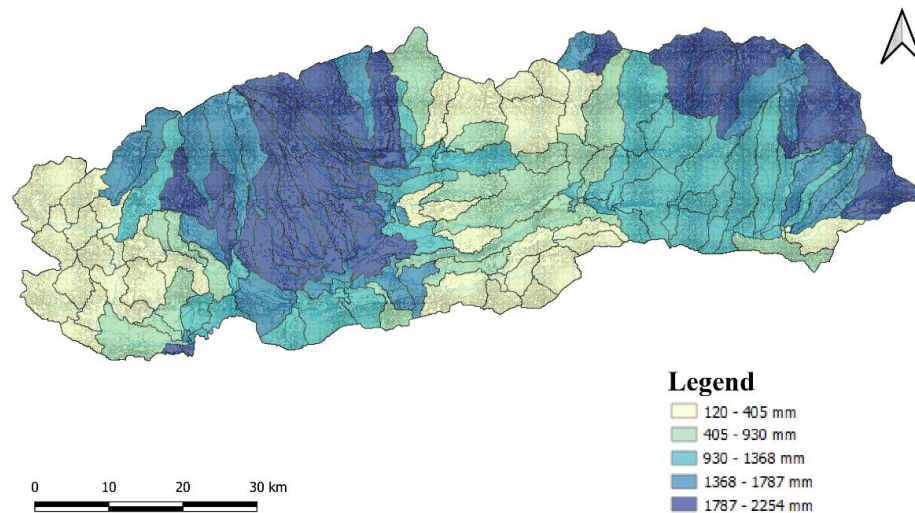
Water Recharge Map of Serayu Map

Figure 6. Water recharge across Serayu watershed

3. Conclusion

The use of SWAT in finding the distribution of water recharge in the Serayu watershed has a good validation level (R^2= 0.86; NSE=0.66). The highest distribution of water recharge is in the upper south of Mount Slamet, while the lowest is in the east of Mount Slamet. This is possible due to different types of land cover. So that land cover management, especially in the upstream area of the watershed, is very important in relation to water resource conservation.

Acknowledgment

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