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

by Afik Hardanto

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

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[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 $mm.d^{-1}$

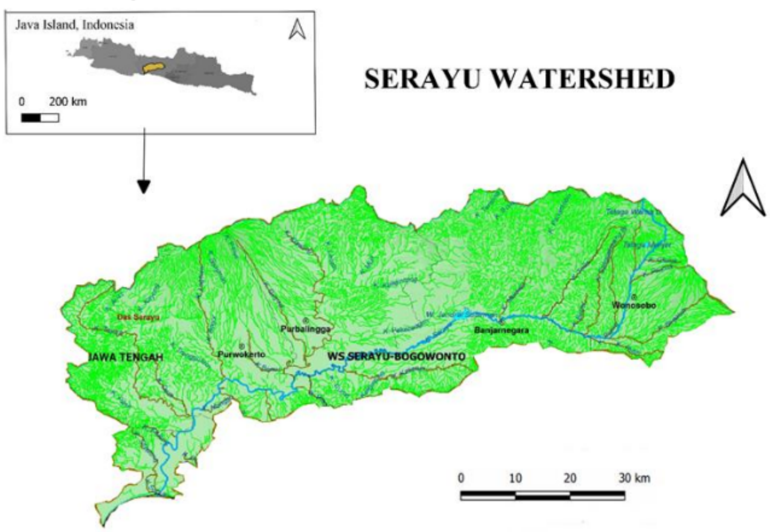


Figure 1. *Study region of Serayu watershed*

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 R^2 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 R^2 and NSE coefficients. The R^2 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).

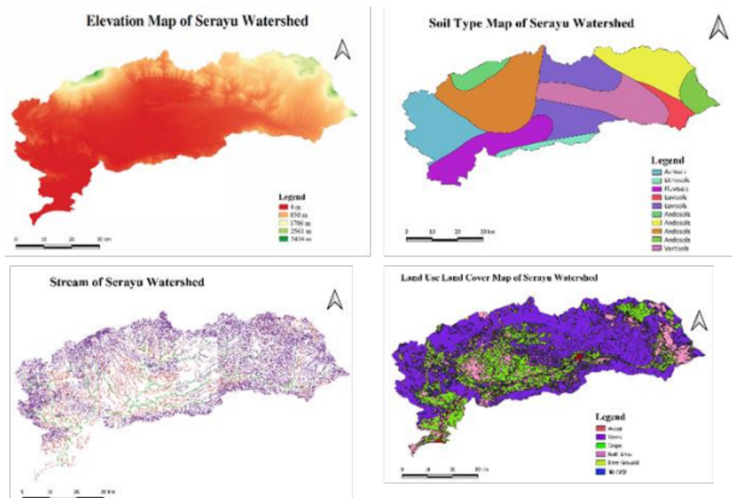
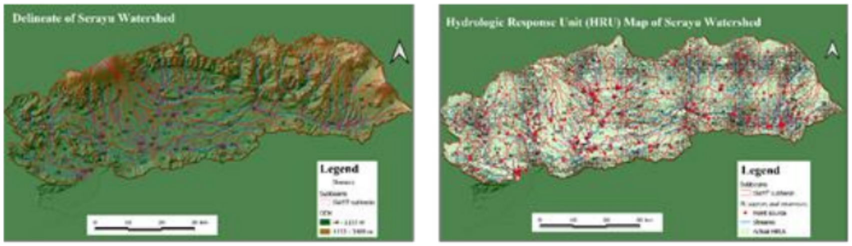


Figure 2. Thematic spatial map for SWAT model input.

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).



a b

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

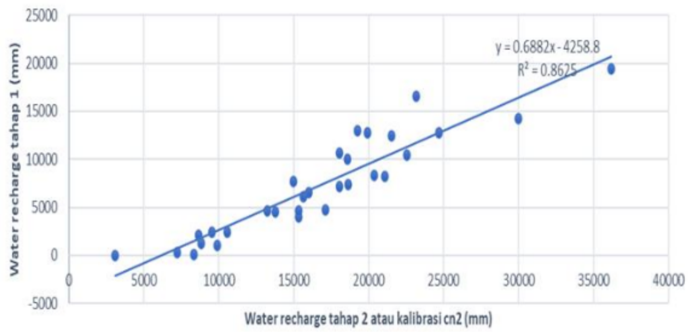


Figure 4. Koefisien determinasi (R^2) water recharge of Serayu watershed

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].

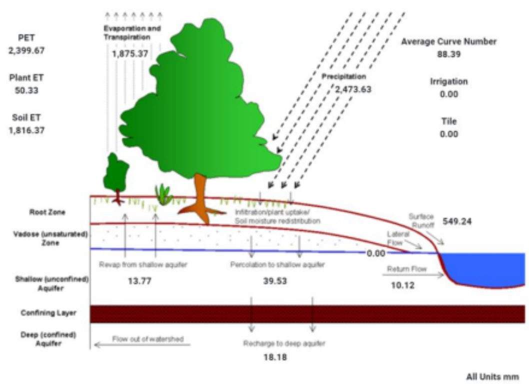


Figure 5. Water balance diagram of SWAT modelling result

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].

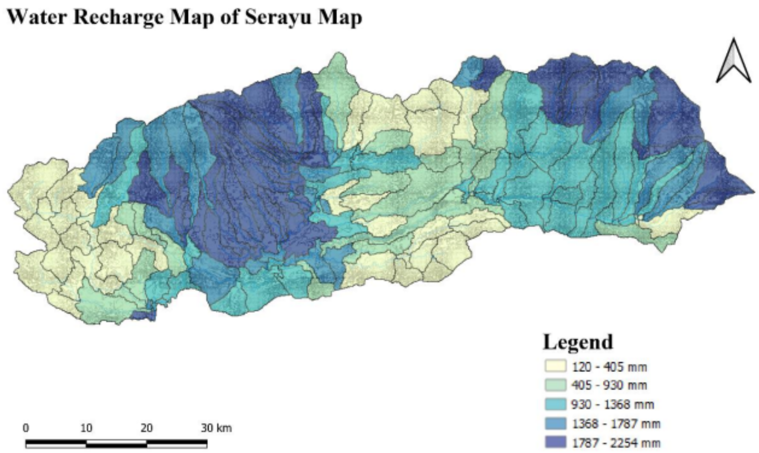


Figure 6. Water recharge across Serayu watershed

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.

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References

[1] Ika 2016 Ratusan Daerah Aliran Sungai di Indonesia Kritis | Universitas Gadjah Mada
[2] Sriyana I 2018 Evaluation of watershed carrying capacity for watershed management (a case study on Bodri watershed, Central Java, Indonesia) ed P Hajek, A L Han, S Kristiawan, W T Chan, M b. Ismail, B S Gan, R Sriravindrarajah and B A Hidayat MATEC Web Conf. 195 05003
[3] Susanti Y, Syafrudin S and Helmi M 2019 Soil Erosion Modelling at Watershed Level in Indonesia: a Review ed Hadiyanto, Budi Warsito and Maryono E3S Web Conf. 125 01008
[4] Suhartanto E, Priyantoro D and Itratip 2012 Studi Penilaian Kondisi DAS dan Implikasinya Terhadap Fluktuasi Debit Sungai (Studi Kasus Pada Sub DAS Jangkok Pulau Lombok) 3 5
[5] Kementerian Lingkungan Hidup dan Kehutanan 2019 Mengenal Status dan Arahan Pengelolaan Jasa Lingkungan DAS Serayu Pusat Pengendalian Ekoregion Jawa Kementerian Lingkungan Hidup dan Kehutanan
[6] Jariyah N A and Pramono I B 2013 Susceptibility of Socio Economic and Biophysical in Serayu Watershed Penelitian Sosial dan Ekonomi Kehutanan 10 16
[7] Widyastuti M, Riyanto I A, Hendrayana H and Muhammad A S 2017 Potensi Sumber Daya Air DAS Serayu Peningkatan Literasi Informasi Geografi dan Kebencanaan untuk Pembangunan

Pesisir dan Daerah Aliran Sungai Seminar Nasional ke-3 Pengelolaan Pesisir dan DAS (Fakultas Geografi, UGM: Badan Penerbit Fakultas Geografi)
[8] Adhikari R K, Mohanasundaram S and Shrestha S 2020 Impacts of land-use changes on the groundwater recharge in the Ho Chi Minh city, Vietnam Environmental Research 185 109440
[9] Nath B, Ni-Meister W and Choudhury R 2021 Impact of urbanization on land use and land cover change in Guwahati city, India and its implication on declining groundwater level Groundwater for Sustainable Development 12 100500
[10] Akter A, Uddin A M H, Wahid K B and Ahmed S 2020 Predicting groundwater recharge potential zones using geospatial technique Sustain. Water Resour. Manag. 6 24
[11] Dekongmen B W, Anornu G K, Kabo-Bah A T, Larbi I, Sunkari E D, Dile Y T, Agyare A and Gyamfi C 2022 Groundwater recharge estimation and potential recharge mapping in the Afram Plains of Ghana using SWAT and remote sensing techniques Groundwater for Sustainable Development 17 100741
[12] Huang X, Gao L, Crosbie R S, Zhang N, Fu G and Doble R 2019 Groundwater Recharge Prediction Using Linear Regression, Multi-Layer Perception Network, and Deep Learning Water 11 1879
[13] Tonkul S, Baba A, Şimşek C, Durukan S, Demirkesen A C and Tayfur G 2019 Groundwater recharge estimation using HYDRUS 1D model in Alaşehir sub-basin of Gediz Basin in Turkey Environ Monit Assess 191 610
[14] Baker T J and Miller S N 2013 Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed Journal of Hydrology 486 100–11
[15] Mapes K L and Pricope N G 2020 Evaluating SWAT Model Performance for Runoff, Percolation, and Sediment Loss Estimation in Low-Gradient Watersheds of the Atlantic Coastal Plain Hydrology 7 21
[16] Jariyah N A and Pramono I B 2013 Kerentanan Sosial Ekonomi Dan Biofisik Di DAS Serayu: 10 141–56
[17] Ilhami M F and Yusuf M 2021 Optimasi Alokasi Penggunaan Lahan Berbasis Mitigasi Erosi JTITS 9 C127–32
[18] Setiawan, Indarto and Wahyuningsih S 2019 Analisis Neraca Air Pertanian Di Sub DAS Rawatamtu (Analysis of agricultural water balance in Rawatamtu sub-watershed) JPPDAS 3 175–94
[19] D. N. Moriasi, J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel and T. L. Veith 2007 Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations Transactions of the ASABE 50 885–900
[20] Alim N, Tarigan S D, Tejo Baskoro D P and Wahjunie E D 2018 Parameter Sensitivity Test of SWAT Hydrological Model On Two Different Resolutions (A Case Study of Upper Cisadane Subbasin, West Java) J Trop. Soils 23 47–53
[21] Bitew M M and Gebremichael M 2010 Assessment of high-resolution satellite rainfall for streamflow simulation in medium watersheds of the East African highlands (Catchment hydrology/Remote Sensing and GIS)
[22] Ayana E K, Dile Y T, Narasimhan B and Srinivasan R 2019 Dividends in flow prediction improvement using high-resolution soil database Journal of Hydrology: Regional Studies 21 159–75
[23] Pöschke F, Nützmann G, Engesgaard P and Lewandowski J 2018 How does the groundwater influence the water balance of a lowland lake? A field study from Lake Stechlin, north-eastern Germany Limnologica 68 17–25
[24] Wendland E, Gomes L H and Troeger U 2015 Recharge contribution to the Guarani Aquifer System estimated from the water balance method in a representative watershed An. Acad. Bras. Ciênc. 87 595–609

[25] Mengistu T D, Chung I-M, Kim M-G, Chang S W and Lee J E 2022 Impacts and Implications of Land Use Land Cover Dynamics on Groundwater Recharge and Surface Runoff in East African Watershed Water 14 2068
[26] Nolan B T, Healy R W, Taber P E, Perkins K, Hitt K J and Wolock D M 2007 Factors influencing ground-water recharge in the eastern United States Journal of Hydrology 332 187–205
[27] Basche A D and DeLonge M S 2019 Comparing infiltration rates in soils managed with conventional and alternative farming methods: A meta-analysis PLoS One 14 e0215702
[28] Hardanto A, Mustofa A and Ardiansyah 2023 Rain Water Harvesting Technology: Drinking water fulfillment and water conservation nearby landfill area IOP Conf. Ser.: Earth Environ. Sci. 1155 012011
[29] Nöjd P, Lindroos A-J, Smolander A, Derome J, Lumme I and Helmisaari H-S 2009 Artificial recharge of groundwater through sprinkling infiltration: Impacts on forest soil and the nutrient status and growth of Scots pine Science of The Total Environment 407 3365–71
[30] Perkins K S, Nimmo J R, Medeiros A C, Szutu D J and von Allmen E 2014 Assessing effects of native forest restoration on soil moisture dynamics and potential aquifer recharge, Auwahi, Maui Ecohydrology 7 1437–51

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