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Impacts of Land Use on Runoff and Sediment Dynamics in Tropical Watersheds: A Case Study in Bogowonto Upper Watershed

Nugroho Christanto[1,2], Afid Nur Kholis[1,2], M Anggri Setiawan[1,2], Rohit Sharma[3], Dhruba Pikha Shrestha[4]

[1] *Department of Environmental Geography, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia*
[2] *Center for Disaster Studies, Universitas Gadjah Mada, Yogyakarta, Indonesia*
[3] *Digital Green, New Delhi, India*
[4] *Faculty of ITC University of Twente, the Netherland*

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Corresponding author:
Nugroho Christanto
Email: nchristanto@ugm.ac.id

ABSTRACT

Land use changes in tropical regions have increased, leading to rising environmental stress in Java, Indonesia. Food shortages have driven land conversion and expansion, which increases peak flows during the rainy season and reduces water storage in the dry season, heightening flood risks. Research on integrated catchment hydrology is crucial. This study examines the relationship between land use, runoff, and sediment in the Bogowonto Upper Watershed using SWAT hydrological modeling. The SWAT model helps understand hydrological processes at the watershed scale and the impact of land use changes on runoff and sediment dynamics. The sensitivity of SWAT model parameters varies in the Bogowonto Upper Watershed. Runoff sensitivity analysis indicates a +62% increase with a 50% change in CN value, showing high sensitivity. A 50% change in vegetation cover results in a +50% model output, indicating moderate sensitivity. Slope, Ksat (saturated hydraulic conductivity), and bulk density are fairly sensitive, while AWC is slightly sensitive. For sediment, a 50% increase in CN value results in a +47% change, and a 50% increase in vegetation cover leads to a +58% model output, showing moderate sensitivity. The model, run from 2014-2019, shows excellent accuracy with NSE of 0.82, RRMSE of 0.43, R^2 of 0.83, and PBIAS of 9.8%.

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1. INTRODUCTION

Tropical watersheds have a crucial role in the regulation of water supplies (Abbaszadeh et al., 2023), the preservation of biodiversity (D. M. Amatya & M. K. Jha, 2011; Zhao et al., 2024), and the maintenance of livelihoods for millions of people around the world. Nevertheless, these watersheds are encountering escalating stresses due to human activities, such as deforestation, agricultural growth, urbanization, and infrastructural development. The alterations in land use have a dramatic effect on hydrological processes, including the flow of water and the dynamics of erosion, which have substantial consequences for the health of ecosystems, the purity of water, and the socio-economic well-being of communities (Christanto et al., 2018, 2019; Sun et al., 2015; sunandar et al., 2014; Yustika et al., 2012; Zhao et al., 2024). This study aims to thoroughly investigate the effects of land use on the flow of water and the wearing away of soil in tropical watersheds. It will utilize the Bogowonto Upper Watershed case studies to support its findings.

Land use change is mainly caused by agricultural expansion, logging, and infrastructure development, significantly contributing to runoff and erosion in tropical watersheds (Abbaszadeh et al., 2023; Pereira et al., n.d., 2022; Rubio et al., 2022). Land use change causes soil instability (Christanto, 2008), intensifies water flow, and accelerates erosion (Asselman et al., 2003; Pandey et al., 2016; Setiawan et al., 2009; Zhang et al., 2017), resulting in soil degradation, reduced fertility (Harashina et al., 2003; Vadas & Powell, 2013), and silt buildup in water bodies. Rapid urbanization and infrastructure development in tropical watersheds lead to substantial alterations in the natural drainage patterns. It will lead to a rise in impermeable surfaces and a disturbance of the interconnectedness of ecosystems. Consequently, there is a substantial rise in runoff and erosion. Urban environments are susceptible to many issues, such as flash floods, stream channel erosion, and water quality degradation. These problems can endanger Purworejo City areas' infrastructure, property, and public health. Some reports show that several villages are threatened by floods, such as 10 villages in Purwodadi Sub-District (Bencana Kesehatan.net, 2020). The flood not only threatened the villages but also Yogyakarta International Airport (YIA). The Indonesian government is now speeding up the project to mitigate the Bogowonoto flood to protect YIA (Metronews.com, 2023). Significantly, the relationship between land use, runoff, and sediment dynamics in Tropical Environments remains poorly comprehended. Thus, hydrological modeling assumes significance. This study aims to examine the impact of land use towards runoff and sediment in a tropical climate with Bogowonto Upper Watershed as a case study by means of hydrological modeling.

2. METHOD

2.1. Study Area

The Bogowonto Upper Watershed is situated in Central Java, Indonesia (Figure 1) (BBWS SO, 2019). The overall drainage basin covers an estimated size of 333,995 square kilometers. The yearly precipitation in the catchment typically fluctuates between 2500-3500 mm. The topography exhibits a combination of different types. However, due to its location in a hilly area, most of the watershed area is characterized by steep slopes. Figure 1 displays the geographical map of the research region. Most of the watershed area is situated in regions with high elevations. Overall, the human-caused impacts on the Bogowonto Upper Watersheds are moderate. However, the National Strategic planning for developing one of the tallest reservoirs in Indonesia and the development of Badan Otorita Borobudur may accelerate the development of this area. Thus, the Bogowonto Upper Watershed in the tropical area of Indonesia is optimal for hydrological modeling research.

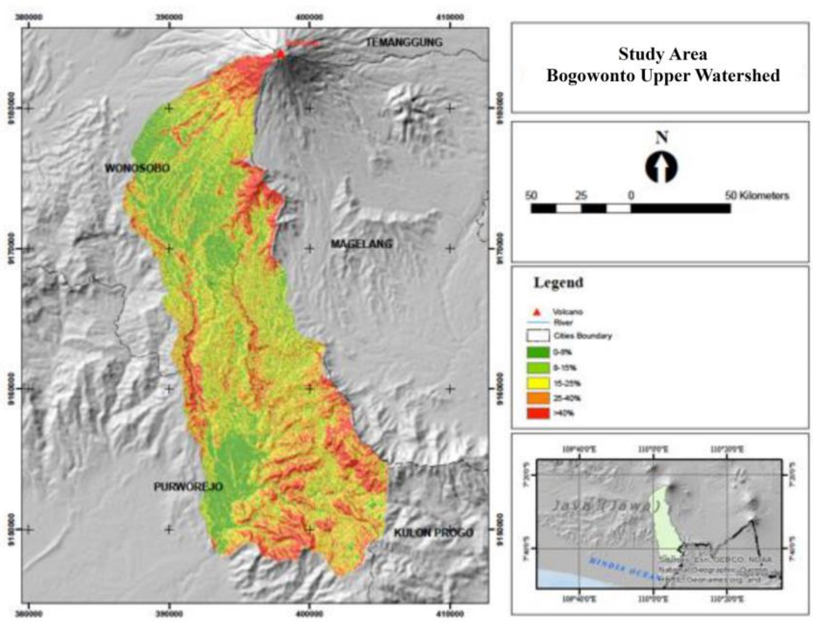

Figure 1. Bogowonto Upper Watershed

2.2. Equation

SWAT utilizes physiographic and hydro-meteorological data to perform rainfall-runoff modeling (Arnold, Moriasi, et al., 2012). The digital elevation model (DEM) is essential for delineating watersheds and sub-watersheds (dos R. Pereira et al., 2016). To create hydrologic response units (HRUs), three specific types of maps are required: land use/land cover (LULC), slope (derived from digital elevation model), and soil data (Arnold, Kiniry, et al., 2012b, 2012a; Arnold, Moriasi, et al., 2012; Gassman et al., 2007; Neitsch et al., 2011). The DEMNAS was acquired for the present investigation. The accuracy of this Digital Elevation Model (DEM) has been evaluated by comparing it with other globally available DEMs. The DEMNAS dataset can be accessed with a resolution of 8.1 meters and covers the entire Indonesian region. This study employs satellite imagery from Landsat 8 2019, which has a spatial resolution of 15 meters, to examine land use and land cover (LULC). The DEMNAS data is obtained from the Indonesian Geospatial Agency (BIG). The soil data is obtained through soil collection and laboratory analysis, utilizing a pedogeomorphological approach. The SWAT approach incorporates physiographic and hydro-meteorological data to simulate the rainfall-runoff process. The digital elevation model (DEM) is essential for delineating watersheds and sub-watersheds. To create hydrologic response units (HRUs), three specific types of maps are required: land use/land cover (LULC), slope (derived from digital elevation model), and soil data.

The SWAT model is a process-based semi-distributed model capable of simulating the water dynamics within a watershed. When the watershed is divided into hydrologic response units (HRUs), the SWAT model is semi-distributed. On the other hand, SWAT is also a persistent model capable of simulating long-term processes. The research methods comprised three primary phases: pre-fieldwork, fieldwork, and post-fieldwork (including model simulation and analysis). Figure 2 shows the research flowchart. The pre-fieldwork and fieldwork stages are crucial as they significantly impact the success rate of the model simulation process. Thoroughly preparing for fieldwork will enhance the efficiency of data collection techniques and sampling procedures in the field.

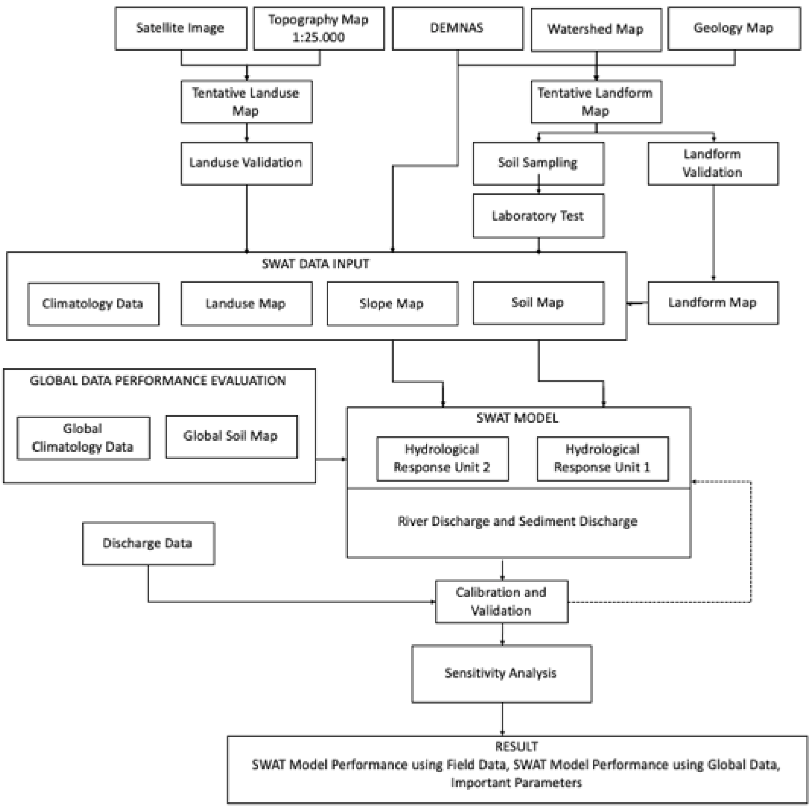

Figure 2. Research flowchart

2.3. Sensitivity Analysis

Sensitivity analysis is a tool used to evaluate the influence of input parameters on the output of a model. It is useful not only for developing and validating models but also for reducing uncertainty (Hamby, 1994). Consequently, conducting a sensitivity analysis allows for a more comprehensive understanding of the input parameters that have a greater impact on the model's output. This research assessed 3 main input parameters to analyze the sensitive parameters. They are slope, soil, and land use. These 3 main input parameters will be independent variables. Assessment will be done by manual sensitivity analysis. Each value of the parameter will be changed by increasing/decreasing value by 25%, 50%, 75%, and 100%. The result of the model performance will be compared based on the parameters decreasing/increasing to see which parameters yield the highest changes. The higher the changes the more sensitive the parameters.

2.4. Model Performance

Model performance is evaluated using quantitative measurements such as graphic comparisons and statistical testing. An accuracy criterion can assess the agreement between predicted and observed outputs during calibration. Therefore, it is possible to determine the goodness of fit and the ideal parameter values for each set of parameters. The statistical measures used to compare the simulated and actual results were the coefficient of determination (R2), Nash–Sutcliffe efficiency (NSE) (equation 1) (Nash & Sutcliffe, 1970), and percent bias (PBIAS) (Motovilov et al., 1999; Schilirò et al., 2016) (equation 2). Sensitivity analysis can determine the various elements that influence model outputs and reactions. Statistical analysis (SA) also examines the correlations between parameters, the range of values that are preferred, and the variability across different regions, all of which impact the output of the model. Model performance is evaluated using quantitative measurements such as graphic comparisons and statistical testing. A criterion for accuracy can be used to compare the predicted and observed results during the calibration process. Therefore, it is possible to determine the goodness of fit and the ideal parameter values for each set of parameters. The model's performance was assessed by comparing the simulated and actual results using the coefficient of determination (R2), Nash-Sutcliffe efficiency (NSE) (equation 1), and percent bias (PBIAS) (equation 2). Sensitivity analysis is a method used to identify and quantify the different factors that have an impact on the results and responses of a model. Statistical analysis also investigates the relationships between parameters, their ideal range, and the variation across various locations, all of which influence the output of the model.

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right] \tag{1}$$

PBIAS is a statistic that calculates the difference between observed and simulated data, as defined by Equation 1. The model demonstrates an overestimation, as indicated by a negative PBIAS value, which suggests that the simulated values are higher than the measured ones. In contrast, a positive PBIAS indicates that the simulation is lower than the observed value (Boyle et al., 2000; Gupta et al., 1999).

$$\mathrm{PBIAS} = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * (100)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right] \tag{2}$$

3. RESULTS AND DISCUSSION

3.1. Sensitivity Analysis

This paper aims to assess the effectiveness of a semi-distributed hydrological model (SWAT) in Bogowonto Upper Watershed in Central Java. This paper was conducted to evaluate the capability of SWAT hydrological modeling on a tropical watershed and determine the model's sensitivity to essential parameters. The model was performed during the period of 2010-2013 for calibration and 2014-2019 to assess the model performance. The result of runoff and sediment in 2019 was then analyzed to learn the impact of land use on hydrological conditions. The curve number (CN) of the cultivated land in the research area significantly affected the river discharge and sediment outputs predicted by the SWAT model. Figure 50 demonstrates the significant impact of adjusting CN (crop) on discharge for all the watersheds, regardless of whether CN increases or decreases. Increasing CN value also substantially increases runoff, while decreases in CN will dramatically reduce the runoff. Runoff is inversely correlated with available water capacity (AWC), saturated hydraulic conductivity (KSAT), bulk density, and soil depth. The study revealed that soil physical characteristics are crucial in determining runoff.

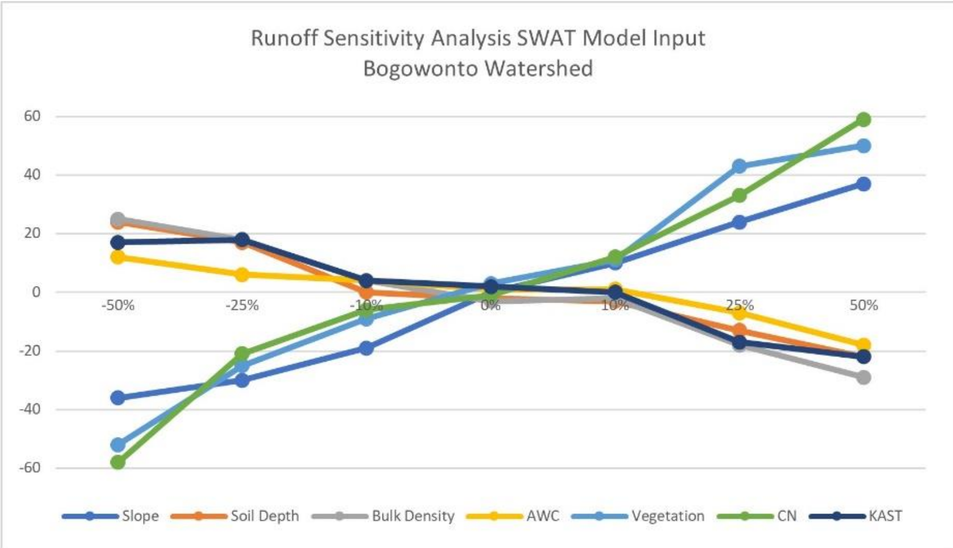

Figure 3. Parameter sensitivity analysis prior to runoff in Bogowonto Upper Watershed

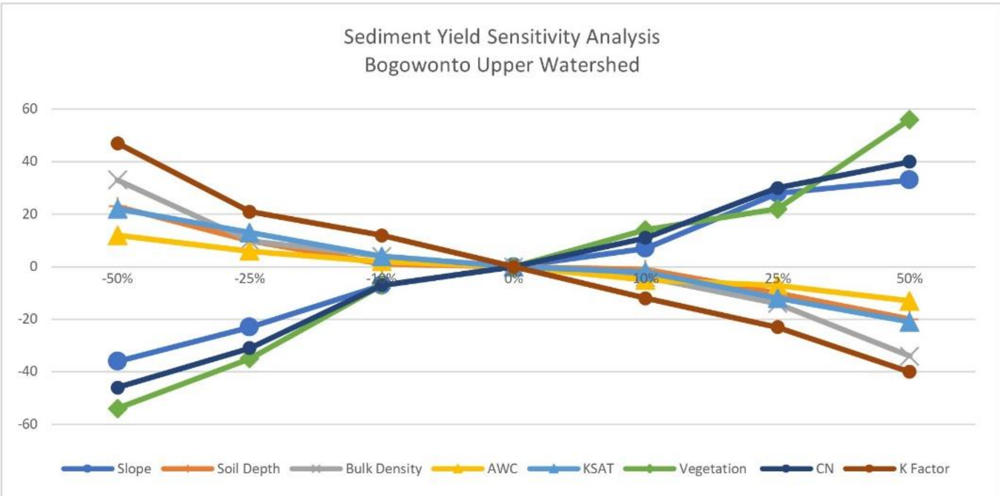

Figure 4. Parameter sensitivity analysis prior to sediment yield in Bogowonto Upper Watershed

Figure 3 demonstrates that the sensitivity of parameters in the SWAT model differs in the Bogowonto Upper Watershed. By applying a 50% increase to each CN input, the model's outcome experiences a 62% increase. Due to changes exceeding 100% of the input, CN is regarded as highly sensitive. The vegetation cover (land-use) increases by 50% when the input of changes is increased by 50%. Therefore, vegetation is regarded as moderately sensitive. Meanwhile, slope variables, KSat (saturated hydraulic conductivity), and bulk density exhibit a moderate level of sensitivity. At the same time, AWC (available water capacity) shows a modest level of sensitivity since the observed variations are approximately 50 percent.

The sediment yield sensitivity analysis shows a relatively similar pattern where CN, vegetation cover, and slope are more sensitive than soil depth, K Factor, bulk density, AWC, and KSAT, as shown in Figure 4. Increases in CN also significantly increase sediment yield, while decreasing CN will decrease the sediment yield significantly. Sediment yield is inversely proportional to available water capacity AWC, KSAT, bulk density, soil depth, and K Factor. Although the soil's physical parameters were found to be critical for sediment yield, the sensitivity was + 17% to 33%, with 59% percent input changes for all watersheds. This condition means that soil properties are generally slightly sensitive to moderate sensitive in sediment yield simulation. With an input of 50% on CN, the model shows an increase of 47 %. CN is considered moderately sensitive since the changes are less than 100% of the input. For the vegetation cover (land-use), the result of 50% changes in the result of changes shows the sediment increase by 58%. Thus, Vegetation is considered highly sensitive in all watersheds since the changes are more than 100%. At the same time, slope, KSat, and bulk density are moderately sensitive, and AWC is slightly sensitive since the changes are approximately 50%.

3.2. Validation

The evaluation of the model's performance indicates that the simulated discharge flows are being underestimated. This situation is indicated by the positive PBIAS values of 9.7, as reported by Gupta et al. (1999) and Moriasi et al. (2007). Figure 4 presents a comparison between the discharge flows derived from the Punggangan gauging station, both from simulations and observations. The model's performance indicates that it achieves outstanding outcomes. The analysis reveals the following values: NSE (Nash-Sutcliffe Efficiency) of 0.80, RRMSE (Root Relative Mean Square Error) of 0.42, R2 (Coefficient of Determination) of 0.82, and PBIAS (Percent Bias) of 9.7.

3.3. Impact of Landuse on Runoff and Erosion

The effect of land use on the hydrological response at the Upper Bogowonto Watershed was analyzed individually based on land use. The analysis results showed that land use controls runoff. The impact of land use on runoff is shown in Figure 5. The model shows that settlement contributes 38% to runoff, followed by dryland agriculture with 23 % contribution to runoff and rice field by 18%. Figure 5 shows that mixed gardens, shrubland, and forests contribute less to runoff than other land uses by 8%, 7.7%, and 3.8%, respectively.

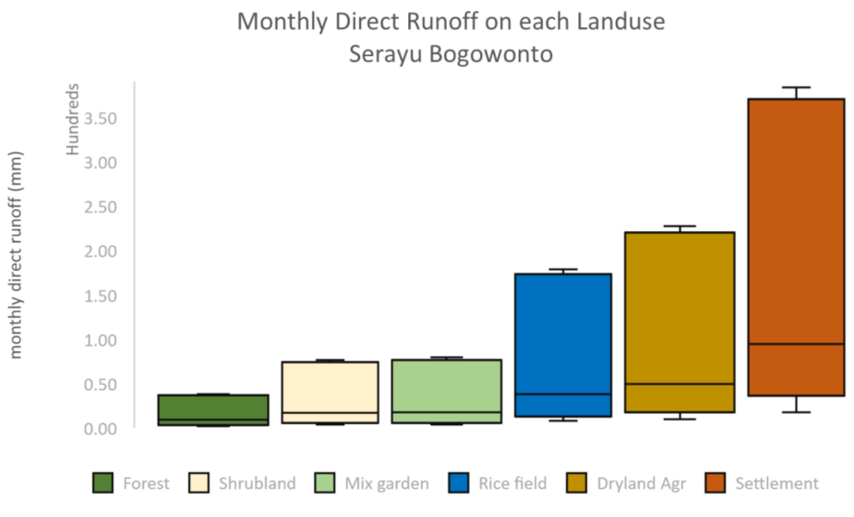

Figure 5. Runoff on each land use in Bogowonto Upper Watershed

The estimates of the amount of surface runoff generated in the 47 sub-basins were classified into five surface runoff groups. Using the land-use maps 2019, the model was performed in 2014-2019, assuming no significant changes. Figure 6 shows that sub-basin 39 falls at class V with very high runoff. For class IV, the result is shown in the sub-basin numbers 2, 16, 18, 23, 30, 34, 36, 43, and 47. The rest belong to classes I, II, and III. This condition prior to land use was dominant in the sub-basin area. Figure 6 shows the runoff distribution on each sub-basin.

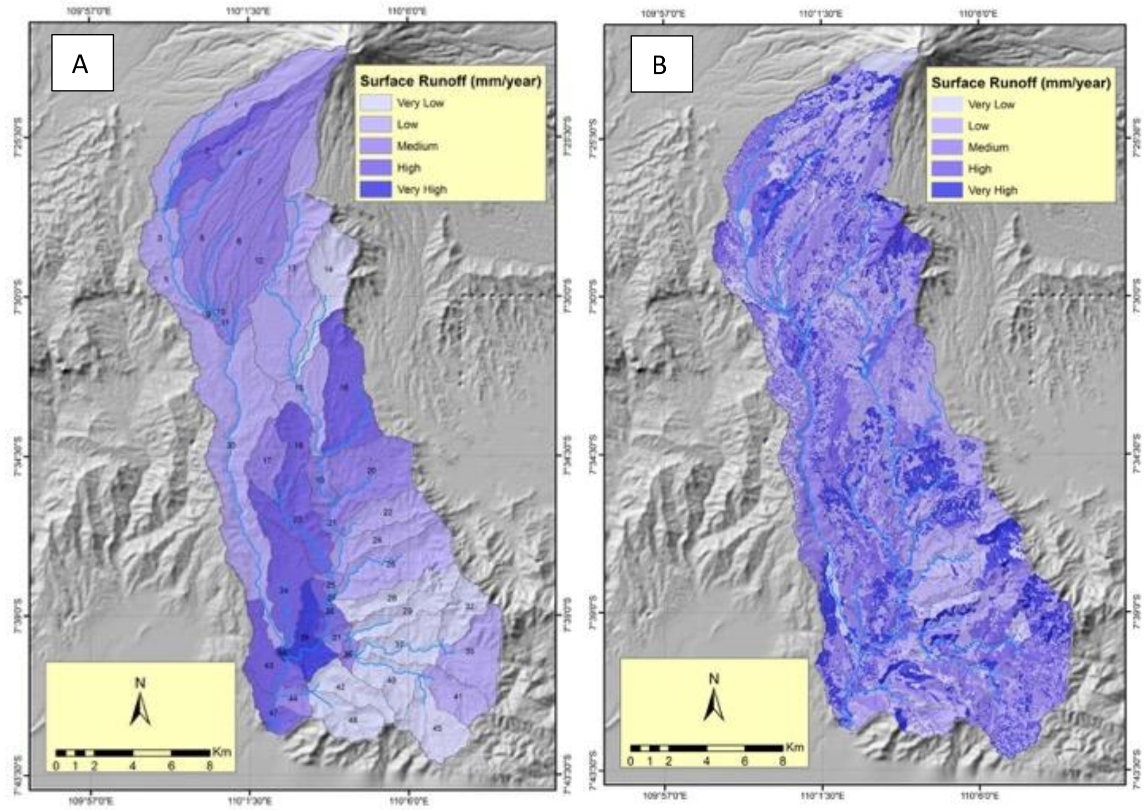

Figure 6. Runoff distribution on each sub-basin (A – left) and on each hydrological respond unit – HRU (B – Right) Bogowonto Upper Watershed

Prior to sediment yield, the effect of land use on the sediment discharge response at the basin scale was assessed based on model simulation. The results of the analysis showed that the sediment is also controlled by land use. The impact of land use on the sediment is shown in Figure 7. The model shows that dryland agriculture contributes to high sediment discharge by 70%, followed by shrubland by 22%. From the simulation, we can understand that the rice field has a lesser impact on sediment yield by 4%, while settlement, mixed gardens, and forests have a low contribution to sediment yield compared to other land uses by less than 2.8%.

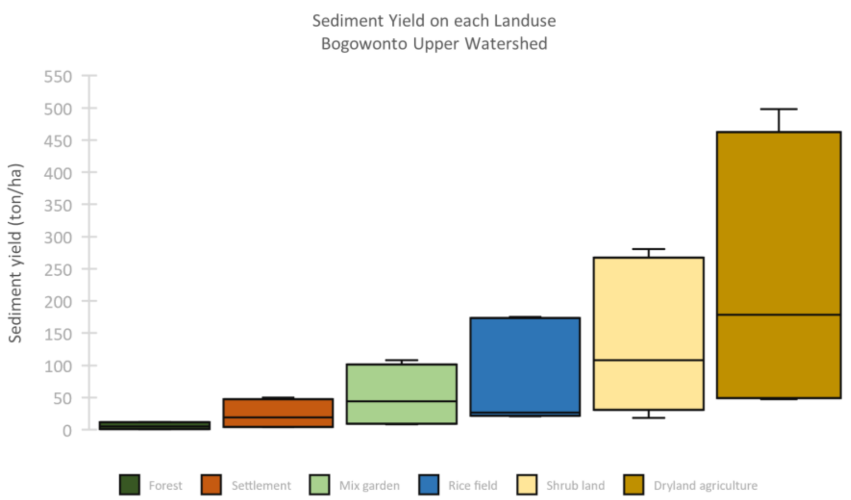

Figure 7. sediment yield in Bogowonto Upper Watershed prior to Landuse

The SWAT model was applied to estimate the amount of sediment generated from 47 sub-basins. The sub-basin sediment was classified into five surface runoff groups. Figure 8-a shows that sub-basin numbers 1,4,14, and 32 belong to class V with a very high sediment yield. For class IV, the result shows in the sub-basin of 2,13, 24, 29, and 39. The rest belong to classes I, II, and III. This condition prior to land use is dominant in the sub-basin area; they are dryland agriculture in classes IV and V. Figure 8 shows the sediment yield distribution on each sub-basin.

In terms of watershed management, HRU assessments were applied. The results of this study show that land use plays a dominant role in the sediment yield of the Bogowonto Upper Watershed. Figure 8-b shows the spatial distribution of sediment contribution prior to land-use distribution in the form of HRU. We learned that from the HRU, we can select priority areas to improve watershed response. The best management practice for watershed management is not solely applied based on sediment in the sub-basin but also considers HRU to perform a precise action toward watershed management.

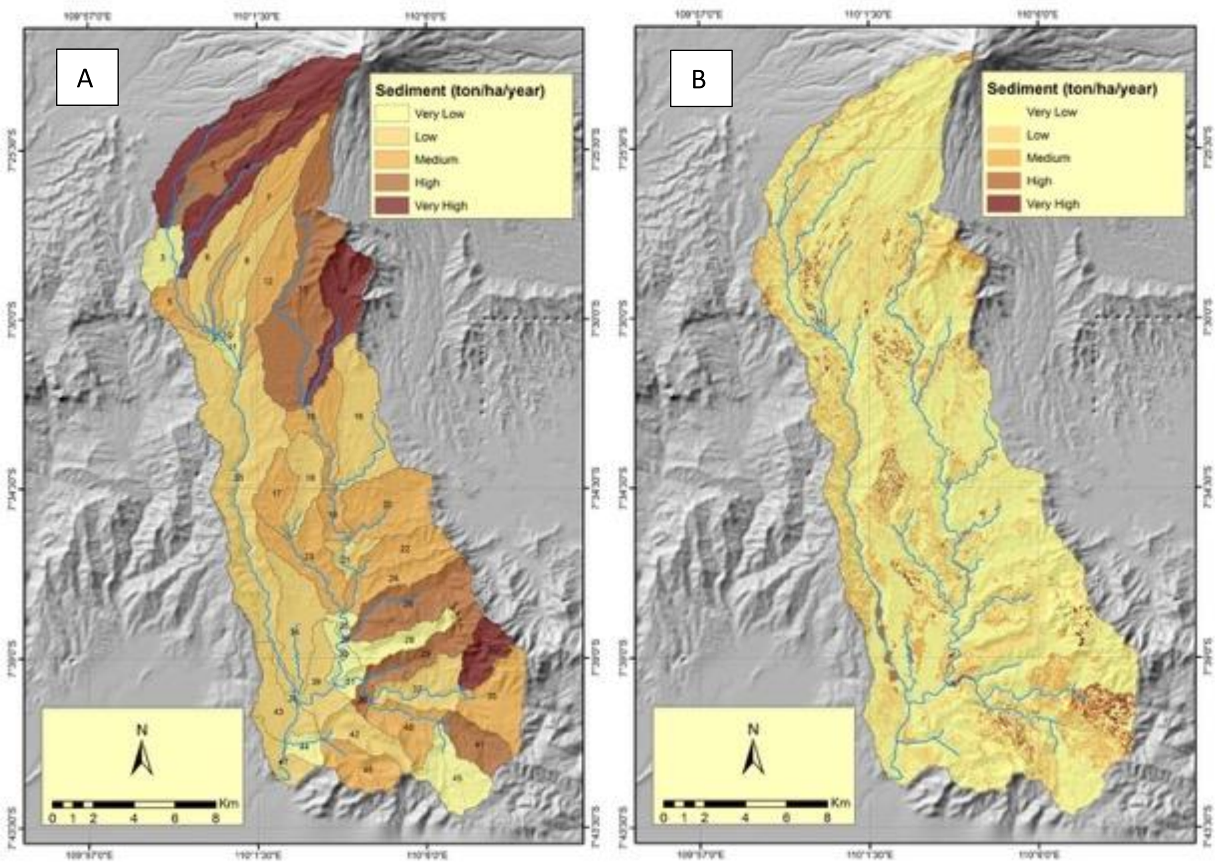

Figure 8. A. Sediment yield on each sub-basin, Bogowonto Upper Watershed, B. Sediment yield based on HRU

4. CONCLUSIONS

This study investigates the correlation between land use and the occurrence of runoff and sediment in a tropical environment. The study's results demonstrate that land use significantly impacts runoff and sediment dynamics in the studied area. The Curve Number (CN) and vegetation cover are identified as highly sensitive parameters, while the soil physical parameter exhibits moderate to slightly sensitive characteristics. The findings also indicate that various land use practices influence the runoff and sediment. The analysis suggests that land use significantly impacts the amount of runoff. The relationship between land use and runoff reveals that settlements have the greatest impact on runoff by 38%, followed by dryland agriculture (23%) and rice fields (18%). However, the model indicates that land uses such as mixed gardens, shrublands, and forests contribute less to runoff than other land types by 8%, 7.7%, and 3.8%, respectively. The research shows that land use also influences sediment. According to the model, dryland agriculture significantly contributes to sediment discharge by 70%, with shrubland having a medium impact on sediment by 22% contribution. Based on the simulation, we can conclude that the rice field low influences sediment yield with a 4% contribution. In contrast, housing, mixed gardens, and woodlands have a minimal impact on sediment yield compared to other land uses by less than 2.8%. The model's result clearly shows that the SWAT hydrological model is appropriate for hydrological simulation in tropical environments at a basin scale.

5. REFERENCES

Abbaszadeh, M., Bazrafshan, O., Mahdavi, R., Sardooi, E. R., & Jamshidi, S. (2023). Modeling Future Hydrological Characteristics Based on Land Use/Land Cover and Climate Changes Using the SWAT Model. Water Resources Management, 37(10), 4177–4194. https://doi.org/10.1007/S11269-023-03545-6

Arnold, J. G., Kiniry, J. R., Srinivasan, R., Williams, J. R., Haney, E. B., & Neitsch, S. L. (2012a). Soil and Water Assessment Tool: Input/Output Files. http://swat.tamu.edu/media/69296/SWAT-IO-Documentation-2012.pdf

Arnold, J. G., Kiniry, J. R., Srinivasan, R., Williams, J. R., Haney, E. B., & Neitsch, S. L. (2012b). Soil and Water Assessment Tool (SWAT) User's Manual, Version 2012. https://doi.org/10.1007/978-0-387-35973-1_1231

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M., Srinivasan, R., Santhi, C., Harmel, D., Griensven, A. van, Liew, M. Van, Kannan, N., & Jha, M. K. (2012). SWAT: Model use, calibration, and validation. Biological Systems Engineering: Papers and Publications.

Asselman, N. E. M., Middelkoop, H., & van Dijk, P. M. (2003). The impact of changes in climate and land use on soil erosion, transport and deposition of suspended sediment in the River Rhine. Hydrological Processes, 17(16), 3225–3244. https://doi.org/10.1002/hyp.1384

BBWS SO, T. (2019). Laporan TKPSDA WS Serayu Bogowonto.

Bencana Kesehatan.net. (2020). 10 Desa Terendam Banjir Luapan Sungai Bogowonto. 2020.

Boyle, D. P., Gupta, H. V., & Sorooshian, S. (2000). Toward improved calibration of hydrologic models: Combining the strengths of manual and automatic methods. Water Resources Research, 36(12), 3663–3674. https://doi.org/10.1029/2000WR900207

Christanto, N. (2008). Hydrological – Slope Stability Modeling for Landslide Hazard Assessment by means of GIS and Remote Sensing Data in Geo-Information for Spatial Planning and Risk Management. https://www.itc.nl/library/papers_2008/msc/ugm/nugroho.pdf

Christanto, N., Setiawan, M. A., Nurkholis, A., Istikhomah, S., Anajib, D. W., & Purnomo, A. D. (2019). Rainfall-Runoff and Sediment Yield Modelling in Volcanic catchment using SWAT, a Case Study in Opak Watershed. IOP Conference Series: Earth and Environmental Science, 256(1). https://doi.org/10.1088/1755-1315/256/1/012015

Christanto, N., Setiawan, M. A., Nurkholis, A., Istiqomah, S., Sartohadi, J., & Hadi, M. P. (2018). Analisis Laju Sedimen DAS Serayu Hulu dengan Menggunakan Model SWAT. Majalah Geografi Indonesia, 32(1), 50. https://doi.org/10.22146/mgi.32280

D. M. Amatya, & M. K. Jha. (2011). Evaluating the SWAT Model for a Low-Gradient Forested Watershed in Coastal South Carolina. Transactions of the ASABE, 54(6), 2151–2163. https://doi.org/10.13031/2013.40671

dos R. Pereira, D., Martinez, M. A., Pruski, F. F., & da Silva, D. D. (2016). Hydrological simulation in a basin of typical tropical climate and soil using the SWAT model part I: Calibration and validation tests. Journal of Hydrology: Regional Studies, 7, 14–37. https://doi.org/10.1016/j.ejrh.2016.05.002

Gassman, P. W., Reyes, M. R., Green, C. H., & Arnold, J. G. (2007). SWAT: Hystorical development, applications, and future research directions. 50(4), 1211–1250.

Gupta, H. V., Sorooshian, S., & Yapo, P. O. (1999). Status of Automatic Calibration for Hydrologic Models: Comparison with Multilevel Expert Calibration. Journal of Hydrologic Engineering, 4(2), 135–143. https://doi.org/10.1061/(ASCE)1084-0699(1999)4:2(135)

Hamby, D. M. (1994). A review of techniques for parameter sensitivity analysis of environmental models. Environmental Monitoring and Assessment, 32(2), 135–154. https://doi.org/10.1007/BF00547132
Harashina, K., Takeuchi, K., Tsunekawa, A., & Arifin, H. S. (2003). Nitrogen flows due to human activities in the Cianjur-Cisokan watershed area in the middle Citarum drainage basin, West Java, Indonesia: A case study at hamlet scale. Agriculture, Ecosystems and Environment, 100(1–3), 75–90. https://doi.org/10.1016/S0167-8809(03)00173-7
Metronews.com. (2023). Kementerian PUPR Kebut Proyek Pengendalian Banjir Bandara YIA.
Motovilov, Y. G., Gottschalk, L., Engeland, K., & Rodhe, A. (1999). Validation of a distributed hydrological model against spatial observations. Agricultural and Forest Meteorology, 98–99, 257–277. https://doi.org/10.1016/S0168-1923(99)00102-1
Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part I — A discussion of principles. Journal of Hydrology, 10(3), 282–290. https://doi.org/10.1016/0022-1694(70)90255-6
Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. (2011). Soil and Water Assessment Tool Theoretical Documentation Version 2009 Texas Water Resources Institute. http://swat.tamu.edu/media/99192/swat2009-theory.pdf
Pandey, A., Himanshu, S. K., Mishra, S. K., & Singh, V. P. (2016). Physically based soil erosion and sediment yield models revisited. CATENA, 147, 595–620. https://doi.org/10.1016/j.catena.2016.08.002
Pereira, P., Gomes, E., & Rocha, J. (2022). Mapping and Forecasting Land Use: The Present and Future of Planning. Mapping and Forecasting Land Use: The Present and Future of Planning, 1–325. https://doi.org/10.1016/C2020-0-02839-2
Pereira, P., Gomes, E., & Rocha, J. G. (n.d.). Mapping and forecasting land use : the present and future of planning.
Rubio, C., Rojas, F., Rubio, M. C., Sales, R., Rubio, F., Verdugo, L., Greco, G., & Martín, F. (2022). Drivers of land use and land cover changes in South America. A review focused on drylands. In Mapping and Forecasting Land Use: The Present and Future of Planning. Elsevier. https://doi.org/10.1016/B978-0-323-90947-1.00004-1
Schilirò, L., Montrasio, L., & Scarascia Mugnozza, G. (2016). Prediction of shallow landslide occurrence: Validation of a physically-based approach through a real case study. Science of The Total Environment, 569, 134–144. https://doi.org/10.1016/j.scitotenv.2016.06.124
Setiawan, M. A., Stoetter, J., Sartohadi, J., & Christanto, N. (2009). The Integrated Soil Erosion Risk Management Model of Central Java , Indonesia. 11.
Sun, L., Nistor, I., & Seidou, O. (2015). Streamflow data assimilation in SWAT model using Extended Kalman Filter. Journal of Hydrology, 531, 671–684. https://doi.org/10.1016/j.jhydrol.2015.10.060
sunandar, ahmad dany, Suhendang, E., . H., Jaya, I. N. S., & . M. (2014). Land Use Optimization in Asahan Watershed with Linear Programming and SWAT Model. International Journal of Sciences: Basic and Applied Research (IJSBAR), 18(1), 63–78. http://gssrr.org/index.php?journal=JournalOfBasicAndApplied&page=article&op=view&path%5B%5D=2678
Vadas, P. A., & Powell, J. M. (2013). Monitoring nutrient loss in runoff from dairy cattle lots. Agriculture, Ecosystems & Environment, 181, 127–133. https://doi.org/10.1016/J.AGEE.2013.09.025
Yustika, R. D., Tarigan, S. D., & Sudadi, U. (2012). SIMULASI MANAJEMEN LAHAN DI DAS CILIWUNG HULU MENGGUNAKAN MODEL SWAT. Informatika Pertanian, 21(2), 71. https://doi.org/10.21082/ip.v21n2.2012.p71-79
Zhang, S., Fan, W., Li, Y., & Yi, Y. (2017). The influence of changes in land use and landscape patterns on soil erosion in a watershed. Science of The Total Environment, 574, 34–45. https://doi.org/10.1016/j.scitotenv.2016.09.024
Zhao, J., Zhang, N., Liu, Z., Zhang, Q., & Shang, C. (2024). SWAT model applications: From hydrological processes to ecosystem services. Science of The Total Environment, 931, 172605. https://doi.org/10.1016/J.SCITOTENV.2024.172605