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IMPROVING INFILTRATION MODELING FOR PAPUA'S SMALL WATERSHED BY USING RSTUDIO SOFTWARE ANALYSIS

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ABSTRACT: Eco-hydrological processes in watersheds are essential for policy development and social growth despite growing environmental concerns. These processes represent a dynamic interaction between the hydrological cycle and ecological elements, with infiltration as one of the important components. According to preliminary studies, the availability of infiltration rate data holds significant importance for irrigation planning, flood management, and water resource studies. Presently, there is a global decrease in hydrological data due to the abundance of water resources in Papua. Existing literature emphasizes the need to evaluate the Kostiakov and Green Ampt models in varied soil textures in Papua, particularly within small watersheds. Therefore, this research compared the performance of the two models on each soil texture using the Hydrological Soil Group classification. It also analyzed modifications for models with unsatisfactory performance through the use of RStudio software analysis with k-fold cross-validation. The results showed that the Green Ampt model performs better than the Kostiakov model for nine soil textures, with average performance values of 0.800 (R), 0.636 (NSE), and 0.588 (RSR). Although the Kostiakov model initially underperformed, it was enhanced to the Pristianto Model by integrating soil properties such as water content (w), porosity (n) and sand content (Sn). Further evaluation in other small watersheds is needed to confirm its robustness. In conclusion, this research filled hydrology data gaps in Papua, which resulted in an infiltration model tailored to the soil characteristics of small watersheds.

Keywords: Performance model, Kostiakov model, Green Ampt model, Small watershed, Modification model, K-fold cross-validation, RStudio software analysis

1. INTRODUCTION

Eco-hydrological processes in watersheds are important to prevent environmental challenges associated with policy formulation in the society. These processes include a dynamic interaction between the hydrological cycle and the ecological components of a watershed, with infiltration considered as one of the essential elements [1]. Infiltration, representing the process through which water penetrates the soil surface, plays a significant role in groundwater recharge. According to Subramanya, water moves through four distinct soil zones with varying moisture levels during this process. Infiltration starts in a wet soil layer and transitions through a zone where moisture decreases with unsaturated flow. It eventually reaches the deepest layer near the maximum moisture capacity of the soil, with the depth of penetration influenced by incoming water volume and soil characteristics [2]. Meanwhile, runoff occurs in all areas and watersheds when infiltration rates are slower than the intensity of rainfall.

According to Rahmati et al., the availability of infiltration rate data is significant in agriculture and water resources engineering. An analysis of the Soil Water Infiltration Global (SWIG) database showed that research contributions on infiltration in Indonesia only constituted 0.47% of the total dataset. Furthermore, data obtained from equatorial climate regions make 7.7%, compared to other areas [3]. According to preliminary studies, field infiltration rates serve as valuable tools for assessing existing infiltration models. Rahmati et al. conducted research comparing infiltration rates in both agricultural and watershed areas to evaluate and refine these models based on regional data patterns. However, this analysis failed to categorize the infiltration data according to soil texture characteristics [3]. Some investigations focused on infiltration model performance without considering soil texture in the watershed. In Indonesia, the SWIG database mainly contained data from Sumbawa Besar, focusing on infiltration models for dry land and rainfed areas [4]. It was further reported that the adoption of the Kostiakov model to assess infiltration performance in river basins, was not as effective as that of the Horton and Philip used on agricultural land in Indonesia [5] and Algeria [6]. The Green Ampt, Horton, and Kostiakov models were not as effective as that of Philip used in Ghana [7] and Nigeria [8]. However, for floodplains within equatorial regions, the Kostiakov model was one of the infiltration models that worked exceptionally well in both countries [9] and [10].

In comparative research, the performance of infiltration models has been extensively studied with a specific focus on soil texture variations as a crucial parameter. The Green Ampt model outperformed that of Philip across ten different soil textures obtained from various Indonesian islands [11]. It was also effective in watersheds with equatorial climates, specifically those with loam soil texture [12], clay and sandy clay loam [13]. However, the Green Ampt model performed poorly on agricultural land with sandy, clay, and sandy loam-textured soils [14], including in watersheds with loamy sand, sandy loam, and sand-textured soils [15]. The Kostiakov infiltration model showed superior performance compared to that of Horton and Philip used on agricultural land with sandy clay loam texture [16]. Although not as good as the Philip model, Kostiakov is effective on clay-textured irrigated land [17].

The Papua region, situated at the eastern end of Indonesia, comprised 2,214 watersheds, mainly small in size, reflecting the unique characteristics of the region [18]. The research conducted by Radhika et al., in this area experienced certain challenges, particularly in calibrating hydrology models and estimating related investigations, due to limited data availability. Despite these data limitations, the Papua region contributed significantly to Indonesian water resources, accounting for approximately 29% of the country annual 2,793 Km^3 of available surface water [19].

Previous research had reported two significant gaps in the analysis of infiltration model performance. The first gap pertains to insufficient coverage of various soil texture types, which were represented by a limited number of research points and lack of attention to multiple watersheds. According to Mishra et al., adequate observation points are crucial for a comprehensive assessment of model performance [20]. In addition, soil texture parameters are essential for selecting the best infiltration model when full ones are unavailable [12]. The second gap is the absence of publications in reputable international journals discussing watershed infiltration rates in the Papua region. This focused on the need for more global attention to this area in scientific literature. A strong rationale for integrating these models within the research framework and subsequent publications realized through a thorough analysis of prior literature comparing Kostiakov and Green Ampt infiltration models in regions similar to Papua, was established.

The first research aimed to compare the performance of the Kostiakov and Green Ampt models across various soil textures in small watersheds in Papua, Indonesia, using the Hydrological Soil Group (HSG) classification. The unique aspect or novelty of this comparison lies in the identification of specific infiltration model parameters designed for each soil texture. The second aim was to analyse modifications for models with unsatisfactory performance, using the RStudio software and k-fold cross-validation. This model modification process was the second novelty or distinctive feature in this research. The subsequent sections of this paper focused on the research significance, method, results, discussion, and conclusion.

2. RESEARCH SIGNIFICANCE

The results of this research hold significant importance for several reasons such as:

1. It contributed to addressing gaps in hydrology data obtained from Papua, Indonesia, leading to improved watershed management practices.
2. The findings established representative infiltration models for small watersheds, specifically considering soil texture classification in equatorial climates.
3. A modified infiltration model designed with respect to the unique soil characteristics was used within the small watershed of Papua.

3. METHOD

3.1 Study Area

The research systematically collected data from 95 observation points across eleven watersheds in the Southwest Papua Province of Indonesia. These watersheds were explicitly located between coordinates 0.8345S to 0.9815S and 131.2389E to 131.3646E. The selection was based on relevant characteristics to ensure a comprehensive geographical representation. Furthermore, accessibility to these watersheds was carefully considered when selecting observation points, due to the dense tropical forests typical of the Papua region. This research also focused on small-scale watersheds, each covering less than 100,000 hectares [21]. These considerations enhanced the correlation between observed hydrology parameters and specific local characteristics. A total of 95 observation points were distributed in the eleven watersheds as follows Rufei 1 (eight points), Rufei 2 (eight points), Boswesen (eight points), Pasar Baru (eight points), Remu (nine points), Klagison (eight points), Klawoguk (nine points), Klasaman (eight points), Klafma (eleven points), Wermon (ten points), and Mariat (eight points).

3.2 Infiltration Rate

In practice, the visualization results of water infiltration vary across different soil textures [22]. Therefore, to obtain accurate infiltration rate data, precise instruments must be used to determine the rate ground surface absorbs water within a defined area [23]. This research used a double-ring infiltrometer, following the SNI 7752:2012 standard set by the Indonesian National Standardization Agency [24]. The instrument ensured valid measurements according to recognized scientific standards. Strict protocols were used for field observations, such as the prohibition of measurements during rainfall. When rain intensity reached or exceeded 12.7 mm/day, the observations were paused for 48 hours before it was continued [16]. The critical parameters for predicting infiltration rate include sludge content, observation duration, clay, water, sand content, and soil density [25].

The theory of Urban Hydrology for Small Watersheds categorizes soil into Hydrologic Soil Groups (HSG), focusing on the minimum infiltration rate after prolonged wetting [26]. Soil surface profiles exerted a significant influence on infiltration rates, with each HSG representing distinct runoff and infiltration characteristics. Each HSG has a consistent pattern of infiltration rates, and the classification processes are as follows:

a. HSG A: sand, loamy sand, sandy loam (low runoff, high infiltration).
b. HSG B: silt loam or loam (moderate runoff and infiltration).
c. HSG C: sandy clay loam (low runoff and infiltration).
d. HSG D: clay loam, silty clay loam, sandy clay, silty clay, clay (high runoff and extremely low infiltration).

The adoption of the Hillel method to determine soil texture includes comparing the masses of the three main soil fractions, sand, silt, and clay, using a soil texture triangle diagram [27].

3.3 Data Analysis

3.3.1 Statistical analysis

This research used Statistical Product and Service Solutions (SPSS) version 25 to analyse critical steps. Data normality was tested using the Shapiro-Wilk method [28], while the suitability of the regression model was evaluated with ANOVA [29], and a nonlinear regression model based on theoretical characteristics was used [29], [30]. The curve estimation tool in SPSS was then used to determine the regression model, providing a robust methodological foundation for understanding variable relationships.

3.3.2 Performance tested infiltration models

The present research conducted a thorough analysis of critical literature and previous investigations to evaluate the performance of the Kostiakov and Green Ampt infiltration models.

a. Kostiakov model

Kostiakov model equation [31]:

$$F = at^{b} \tag{1}$$

Where a>0 and 0<b<1, and F is the cumulative infiltration capacity (cm/jam). Meanwhile t is the infiltration time.

$$f = \alpha t^{-\beta} = (ab)t^{(b-1)} \tag{2}$$

Equation (2) was applied when t≠0, and α, β, a, b are experimentally determined model parameters or graphically.

Parameter estimation procedure [2]:

- Represent the data in the form of plots ln(F) and ln(t) on the y and x-axis, respectively. This approach was used to carry out linear regression analysis, leading to the formulation of the equation y=ax+b. Obtain the (a) value of Eq. (2). The (a) value of Eq. (2) was obtained by analysing the coefficient (b) in the linear regression equation (equation y=ax+b). Similarly, analyze the coefficient (a) in the linear regression equation to obtain the b value of Eq. (2) (equation y=ax+b).

b. Green Ampt model

The model equation is Green Ampt [32]:

$$f = K\left(\frac{\Delta\theta\psi + F}{F}\right) \tag{3}$$

Where K is effective hydraulic conductivity (cm/jam), Δθ is soil moisture deficit, ψ is wetting front suction head (cm), and F is the cumulative infiltration capacity (cm/jam).

Subramanya simplified Eq. (3), in respect to parameters m and n as stated in [2]:

$$f = m + \frac{n}{F} \tag{4}$$

Where m and n are the Green Ampt model parameters, and F is the cumulative infiltration capacity (cm/jam).

Parameter estimation procedure [2] includes the following step:

- Represent the data on a plot with f and the inverse of F (1/F) on the y and x-axis, respectively. A linear regression analysis was performed, which led to the formulation of equation y=ax+b. Calculate the m and n values of coefficients (b) and (a) in the linear regression equation, using Eq. (4).

3.3.3 Model evaluation techniques

According to Moriasi et al., evaluation techniques suitable for the watershed model comprised both graphical and statistical methods [33].

1. Visualisation techniques facilitate direct comparisons between simulated and measured data in a graphical context.
2. From a statistical point of view, this research adopted model evaluation techniques using standard regression methods, dimensionless analysis, and error indices. These approaches collective facilitated quantitative assessment of the model performance in adjusting to the observed data, while measuring precision and deviation of predictions.
    a. The Standard Regression method is the main approach used to assess the closeness between simulated and measured data. This method uses the correlation coefficient (R) and the coefficient of determination (R^2). Sugiyono interpreted the correlation coefficient by categorizing the relationship level as shown in Table 1 [34].

Table 1 Interpretation of the correlation coefficient

Interval R	Relationship level
$0.0 \leq R < 0.2$	very low
$0.2 \leq R < 0.4$	Low
$0.4 \leq R < 0.6$	Moderate
$0.6 \leq R < 0.8$	Strong
$0.8 \leq R < 1.0$	Powerful

Note: Source [34]

    b. In the dimensionless approach, the main metric is the Nash-Sutcliffe (NSE) efficiency, a normalised statistic used to evaluate the residual and measured data variance ratio. This efficiency metric indicates the extent to which the plot between the observed and simulation data conforms to a 1:1 line. The NSE value, was calculated using the following equation:

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{mean}\right)^2}\right] \quad (5)$$

description: Yi^{obs}=observation data, Yi^{sim}=simulation data, Y^{mean}=average, and n=total data.

    c. Error Index Analysis: Root Mean Square Error to Observational Standard Deviation Ratio (RSR) standardises the RMSE by incorporating the observational standard deviation.
    This method enhanced the error index with additional information. Specifically, the RSR is determined as the ratio of the RMSE to the standard deviation of the measured data, expressed using the following equation:

$$\mathrm{RSR} = \frac{\mathrm{RSME}}{\mathrm{STDEV_{obs}}} = \left[\frac{\sqrt{\sum_{i=1}^{n}\left(Y_i{}^{obs} - Y_i{}^{sim}\right)^2}}{\sqrt{\sum_{i=1}^{n}\left(Y_i{}^{obs} - Y^{mean}\right)^2}}\right] \quad (6)$$

Table 2 describes the essential steps for selecting the model evaluation technique. Thorough supervision of this process is critical to ensure optimal decision-making.

Table 2 Analysis of performance ratings for the watershed model

Rating	RSR	NSE
Very Good	0.0< RSR< 0.5	0.7< NSE<1.0
Good	0.5<RSR<0.6	0.65<NSE< 0.75
Satisfactory	0.6<RSR<0.7	0.5<NSE<0.65
Unsatisfactory	RSR>0.7	NSE<0.5

Note: Source [33]

3.3.4 K-fold cross validation

Scientific contributions are used to evaluate the performance level of unsatisfactory models. The k-fold cross-validation method is a known approach for enhancing model performance [35]. This method was adopted to divide observation data into k groups by using a random command in the RStudio program, where k-1 serves as the validation set, while the remaining variables were used for modelling, particularly five or ten groups. For example, each group takes a turn as the validation set in a five-group division. A non-linear regression was used to determine the infiltration process. Each new model was evaluated and validated against k-1 data sets to ensure accuracy, enabling a comprehensive assessment of its effectiveness based on the results obtained. Furthermore, model validation in this publication included three parameters namely R, NSE, and RSR [33]. For this stage, the non-linear regression (nls) tool in RStudio version 2023.09.0 Build 463, was adopted.

3.4 Research Stages

This stage started with the collection of soil samples from 95 different observation points in 11 watersheds. Afterwards, rigorous laboratory analyses were conducted to determine the texture classification of the soil. The processing and analysis of soil data was conducted at the Civil Engineering Laboratory, Muhammadiyah University of Sorong.

Following the initial steps, a field infiltration assessment was conducted using a double-ring infiltrometer. The acquired data was generated over 32-time intervals, as specified by the SNI protocol. This process ensured that each observation point produced 32 data entries according to the guidelines. Subsequently, the infiltration data gathered from 95 observation points was then arranged based on the respective soil texture, determined by the HSG criteria [35].

The statistical analysis step comprised several tests conducted to evaluate nonlinear regression models, including normality, ANOVA analysis, and model coefficient tests. Furthermore, the performance of two infiltration models, namely Kostiakov and Green Ampt was compared to the existing models in each soil texture group [33]. RStudio software analysis with k-fold cross-validation was used to modify and validate the unsatisfactory models [36].

4. RESULTS AND DISCUSSION

4.1 Data Distribution

In the early stages of the research, the HSG classification method was used to categorize the acquired data [35]. The results from the laboratory analysis clarified the identification of each soil texture based on the number of samples obtained from field observation points. A detailed description is stated as follows: clay (eight points), silty loam (two points), sandy loam (one point), silty clay loam (six points), clay loam (23 points), sandy clay loam (12 points), clay (17 points), silt loam (nine points), and sandy loam (17 points). Meanwhile, of the eleven soil textures described in the HSG classification system, the examination of 95 soil samples showed nine distinct textures. A thorough examination of the samples failed to yield soil data indicative of a sand or clay sand texture.

4.2 Statistic Analysis

Essential statistical analyses were conducted on infiltration data for each soil texture, ensuring data normality through the Shapiro-Wilk test. Additionally, the relationship between variables X and Y were tested using ANOVA at a 95% confidence level, and validated the impact of its instability with the Coefficient Model. All data with extreme values, such as high errors, were carefully removed. The resulting dataset passed the statistical tests, indicating normal distribution without outliers. However, the time variable proved to be a reliable indicator of infiltration rate at a 95% confidence level. This affirmed its significant influence on infiltration rates in this research.

4.3 Performance Evaluation of Kostiakov and Green Ampt Infiltration Models

The next step was to assess the performance of the Kostiakov and Green Ampt infiltration models in comparison to the existing one following the guidelines outlined in the Engineering Hydrology book [2]. This assessment included a detailed evaluation of soil textures to identify hydrology characteristics, from which performance ratings and parameters from the Kostiakov and Green Ampt models were extracted. To present a comprehensive overview of the model evaluation results, both graphical and statistical descriptions were used, as shown in Tables 3 to 4.

The findings on model performance for areas classified based on its soil textures in small watersheds in Indonesia, are shown from Tables 3 to 4, as follows:

Table 3 Comparison of model performance evaluation.

Soil Texture	Model	Model Evaluation Statistics [33]						
		R	Relationship	NSE Eq.(5)	Performance Rating based on NSE	RSR Eq.(6)	Performance Rating based on RSR	Overall Performance
		Graphical Technique						
clay	K	0.917	powerful	0.392	unsatisfactory	0.780	unsatisfactory	unsatisfactory
	GA	0.746	strong	0.705	good	0.543	Good	Good
silty clay	K	0.887	powerful	-2.765	unsatisfactory	1.940	unsatisfactory	unsatisfactory
	GA	0.907	powerful	0.523	satisfactory	0.691	satisfactory	Satisfactory
silty clay loam	K	0.900	powerful	0.699	good	0.548	Good	Good
	GA	0.654	strong	0.427	unsatisfactory	0.757	unsatisfactory	unsatisfactory
clay loam	K	0.887	powerful	0.691	good	0.556	Good	Good
	GA	0.570	moderate	0.325	unsatisfactory	0.822	unsatisfactory	unsatisfactory
sandy clay	K	0.951	powerful	0.623	satisfactory	0.614	satisfactory	Satisfactory
	GA	0.858	powerful	0.736	good	0.514	Good	Good
sandy clay loam	K	0.922	powerful	0.462	unsatisfactory	0.734	unsatisfactory	unsatisfactory
	GA	0.875	powerful	0.766	very good	0.484	very good	very good
loam	K	0.933	powerful	-1.433	unsatisfactory	1.560	unsatisfactory	unsatisfactory
	GA	0.831	powerful	0.690	good	0.557	Good	Good
silt loam	K	0.866	powerful	-0.057	unsatisfactory	1.028	unsatisfactory	unsatisfactory
	GA	0.820	powerful	0.672	good	0.573	Good	Good
sandy loam	K	0.940	powerful	0.786	very good	0.462	very good	very good
	GA	0.937	powerful	0.878	very good	0.349	very good	very good

Note: K = Kostiakov Model; GA = Green-Ampt Model

1. The performance of the Kostiakov model across different soil textures showed varied performances, ranging from very good (1 of 9 soil textures), good (2 of 9 soil textures), satisfactory (1 of 9 soil textures), and unsatisfactory (5 of 9 soil textures). The average performance values, including 0.911 (R), -0.067 (NSE), and 0.914 (RSR), indicated an overall unsatisfactory performance.
2. The performance of the Green Ampt model showed varying levels across different soil textures, comprising very good (2 of 9 soil textures), good (4 of 9 soil textures), satisfactory (1 of 9 soil textures), and unsatisfactory (2 of 9 soil textures). The average performance values were 0.800 (R), 0.636 (NSE), and 0.588 (RSR), collectively indicating an overall good performance.
3. The Green Ampt models had good performance in predicting the infiltration rate in the research areas.
4. Meanwhile, Kostiakov model required modification to improve its performance.

Table 5 was examined to obtain a more holistic understanding of the final results. The eight investigations used to compare the findings in the Papua region (listed in Table 5) were conducted in locations identical to that of the research, specifically watersheds in areas with equatorial climates. This assumption was based on the following considerations:

1. According to Rubel, all regions in Indonesia were classified under an equatorial climate [37].
2. The theory states that soil infiltration rates are influenced by climatic factors [38].

The results of the global comparison showed that the Green Ampt infiltration model was effective than the Kostiakov model in small watershed areas. The inadequacy of global infiltration data in equatorial climates has been acknowledged [3], and this research in Indonesia aim to contribute to addressing this gap

4.4 Modification of the Kostiakov Model

The Kostiakov model was used to assess the unsatisfactory performance of the research location in Papua, Indonesia. Next, modifications were initiated to the Kostiakov model by adding one or several variables from soil properties (Table 6). These variables were derived from both field observations and the results of laboratory analysis of soil samples. The Kostiakov model was depicted by Eq. (2) [31]:

$$f = \alpha t^{-\beta} = (ab)t^{(b-1)} \tag{2}$$

Incorporating eight variables into parameter (a) within the Kostiakov model equation led to the exploration of variations in one, two, and three-variable integration. The decision to limit integration to three variables was due to the need for simpler, and interpretable models to reduce the risk of overfitting the model has the ability to affect the performance of new data.

Table 6. The variables used to modify the model

Notation	Variable
X_1	field permeability (K)
X_2	water content (w)
X_3	specific gravity (Gs)
X_4	degree of saturation (Sr)
X_5	porosity (n)
X_6	sand content (Sn)
X_7	silt content (Sl)
X_8	clay content (Cl)

This integration process resulted in a new model that showed the best statistical and validation results. The k-1 fold cross-validation method was used to divide the data into five sets, as shown in Table 7.

Table 7 Modified design of the Kostiakov model using the k-1 fold cross-validation method.

Design	Modelling datasets	Validation
1	fold 2, fold 3, fold 4 and fold 5	fold 1
2	fold 1, fold 3, fold 4 and fold 5	fold 2
3	fold 1, fold 2, fold 4 and fold 5	fold 3
4	fold 1, fold 2, fold 3 and fold 5	fold 4
5	fold 1, fold 2, fold 3 and fold 4	fold 5

This evaluation differed from Dagadu, who described the performance analysis of the modified Kostiakov model. The evaluation model was carried out using a constant (c) as shown in equation [39].

Through the RStudio software analysis, the best integration results was obtained for eight variables in the Kostiakov model. After evaluating the six most promising variations of the Kostiakov model modification, the most effective one was selected. The detailed results are shown in Table 8, and based on these findings, the proposed Kostiakov-Small Watersheds or Kostiakov-SW Model (1 to 6) focused on the following significant insights:

1. The performance of the Kostikov model was significantly improved with the incorporation of variables such as water (X_2=w), porosity (X_5=n), sand (X_6=Sn) and clay contents (X_8=Cl). In contrast, variables like field permeability (X_1=K), specific gravity (X_3=Gs), degree of saturation (X_4=Sr), and silt content (X_7=Sl) do not significantly enhance its performance in small watersheds.
2. The clay content variable (X_8=Cl) is not the most effective single determinant, but it becomes dominant when combined with two or

three others, resulting in a better model in small watersheds.

3. The incorporation of soil properties variables into the Kostiakov model improves its practical utility for estimating infiltration rates in small watersheds. The infiltration rate value in small watershed can be estimated due to lack of adequate soil properties.
4. Equation (12) was the most effective among the four modified Kostiakov models with improved performance. The integration of water content (X_2=w), porosity (X_5=n) and sand content (X_6=Sn) into the Kostiakov model yields the best results, in line with similar research on the influence of specific gravity, clay, and silt contents [40] including soil textures on watershed infiltration rates in Padang [41] and Papua [42].

Equation (12) was recommended as the best version of the modified Kostiakov, also known as the Pristianto Model (Kostiakov-Small Watershed Model), showcasing the novelty of this research. Additionally, it was suggested that the Pristianto Model be evaluated with observational data from other equatorial regions to ensure its stability and reliability as an infiltration model, in line with the research roadmap to enhance its accuracy.

5. CONCLUSION

In conclusion, an in-depth data evaluation showed that the Green Ampt model was effectively used to predict the infiltration rate for nine soil textures in small watersheds. Its average performance values were 0.800 (R), 0.636 (NSE), and 0.588 (RSR). Meanwhile, Kostiakov model showed unsatisfactory performance, indicating the need for improvement.

The modification process applied to the Kostiakov model through the integration of soil property variables significantly improved the performance of the Pristianto Model (Kostiakov-Small Watershed Model) when compared to observational data. Specifically, the incorporation of water content (w), porosity (n) and sand content (Sn) variables resulted in a significant satisfactory performance for the modified model. This enhanced performance was evident when comparing the original Kostiakov model of 0.911, -0.067, and 0.914 for R, NSE and RSR with the modified one of 0.876, 0.922, and 0.273. The Pristianto Model was explicitly designed for small watersheds, representing the innovative contribution to water resources engineering. Further evaluations of the Pristianto Model were recommended using observational data from other small watersheds to ascertain its stability and reliability as an infiltration model.

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Table 8 Selection of the best model

Model		Average Value				Overall Performance
		R^2	R	NSE	RSR	
Kostiakov Model $f = \alpha t^{-\beta} = (ab)t^{(b-1)}$	(2)	0.830	0.911	-0.067	0.914	unsatisfactory
Modification 1 $f(t) = (30.932 - 70.942.X_2).t^{-0.263}$	(7)	0.647	0.804	0.706	0.516	good
Modification 2 $f(t) = (190.225.X_5 - 137.910).t^{-0.212}$	(8)	0.718	0.847	0.684	0.539	good
Modification 3 $f(t) = (-61.774 - 42.997.X_2 + 109.624.X_5).t^{-0.215}$	(9)	0.865*	0.930	0.903	0.298	very good
Modification 4 $f(t) = (28.717 - 72.294.X_2 - 20.372.X_8).t^{-0.287}$	(10)	0.794*	0.891	0.858	0.360	very good
Modification 5 $f(t) = (104.633 - 42.118.X_2 + 161.384.X_5 + 14.976.X_8).t^{-0.299}$	(11)	0.735*	0.857	0.911	0.289	very good
Modification 6 $f(t) = (-73.770 - 63.503.X_2 + 141.964.X_5 - 11.062.X_6).t^{-0.261}$	(12)	0.767*	0.876	0.922	0.273	very good

Note: * = R^2 *adjusted value*

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