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Comparison of Several Methods for Analysis Slope Length Index Factor at A Watershed Scale

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ABSTRACT

Slope length and steepness factor index (LS) is one of the parameters for the Universal Soil Loss Equation (USLE) to estimate soil erosion. Currently, several methods for LS analysis, i.e. Wischmeier-Smith, Moore-Nieber, and Desmet – Govers. This study aims to compare the Wischmeier-Smith method, Moore–Nieber method, and Desmet–Govers method to analyze LS in the watershed in Manokwari – West Papua. This research consists of 4 main stages, i.e. data inventory, watershed boundary delineation, LS analysis, and LS comparison. The research showed that the Wischmeier-Smith method gave a higher LS value than the Moore – Nieber method and the Desmet – Govers method. Meanwhile, the Desmet – Gover method gives a lower average LS value than the Wischmeier-Smith method and the Moore – Nieber method. Based on the T-test, the LS produced by the Wischmeier-Smith, Moore-Nieber, and Desmet–Govers methods has significant differences in analyzing LS in the watershed in Manokwari – West Papua.

1. INTRODUCTION

The government has designated the agricultural sector as one of the priority sectors in the National Medium-Term Development Plan (RPJMN) 2020-2024 (Bappenas, 2019). This program is implemented in the Ministry of Agriculture's Strategic Plan 2020-2024, which designates several regions in Indonesia as locations for the Development of National Agricultural Areas (Menteri Pertanian, 2020), including Manokwari Regency in West Papua Province, designated for the development of rice, chili, cocoa, and oil palm crops (Menteri Pertanian, 2018).

Erosion is one of the parameters considered in agricultural planning (Ritung *et al.*, 2011). For instance, food and horticultural crops are highly suitable for cultivation in areas not prone to erosion and are moderately suitable for areas with very light erosion hazards (Ritung *et al.*, 2011). Plantation crops are highly suitable for cultivation in areas with very light erosion hazards and moderately suitable in areas with light to moderate erosion hazards (Ritung *et al.*, 2011).

Currently, more than 80 models have been developed for erosion analysis (Karydas *et al.*, 2014; Raza *et al.*, 2021), but the most commonly used model for erosion analysis is the Universal Soil Loss Equation (USLE) (Hrabalíková & Janeček, 2017; Borrelli *et al.*, 2021). In Indonesia, the USLE model is recommended for land evaluation for agricultural commodity development (Ritung *et al.*, 2011).

The slope length and steepness factor (*LS*) index is one of the parameters used in the USLE model (Wischmeier & Smith, 1978; Ritung *et al.*, 2011; Parveen & Kumar, 2012; Borrelli *et al.*, 2021). Several *LS* analysis methods have been developed, including Wischmeier-Smith (1978), McCool *et al.* (1987), Desmet-Govers (1996), Moore &Wilson

(1992), Moore &Burch (1986), Moore &Nieber (1989), Kumar-Kushwaha (2013), Životić *et al.* (2012), Perović *et al.* (2013), Saygin *et al.* (2013), and Yoshino & Ishioka (2005).

Some *LS* methods cannot be applied to complex topographic conditions (Benavidez *et al.*, 2018). Several *LS* methods recommended for application in complex and diverse topographic conditions include the Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods (Benavidez *et al.*, 2018). Based on this, this study aims to compare the Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods in analyzing *LS* faktor in several watersheds within Manokwari Regency, West Papua Province.

2. MATERIALS AND METHODS

This study was conducted in 8 (eight) main watersheds in Manokwari Regency, West Papua Province, namely Pami Watershed, Nuni Watershed, Wassawui Watershed, Prafi Watershed, Arui Watershed, Mangoapi Watershed, Kasi Watershed, and Wariori Watershed. The study location and the distribution of watersheds in Manokwari Regency were presented in Figures 1 and 2. The materials used in this study included topographic data in the form of 8 m resolution digital elevation models (DEM) and 1:50,000 scale river network data released by the Geospatial Information Agency (BIG). This research consisted of 4 main stages as presented in Figure 3.

1. Data Inventory

This stage aims to collect topographic data in the form of digital elevation models (DEM) and river network maps of Manokwari Regency.

2. Watershed Boundary Delineation

This stage aims to determine the watershed boundaries in Manokwari Regency based on topographic and river network data.

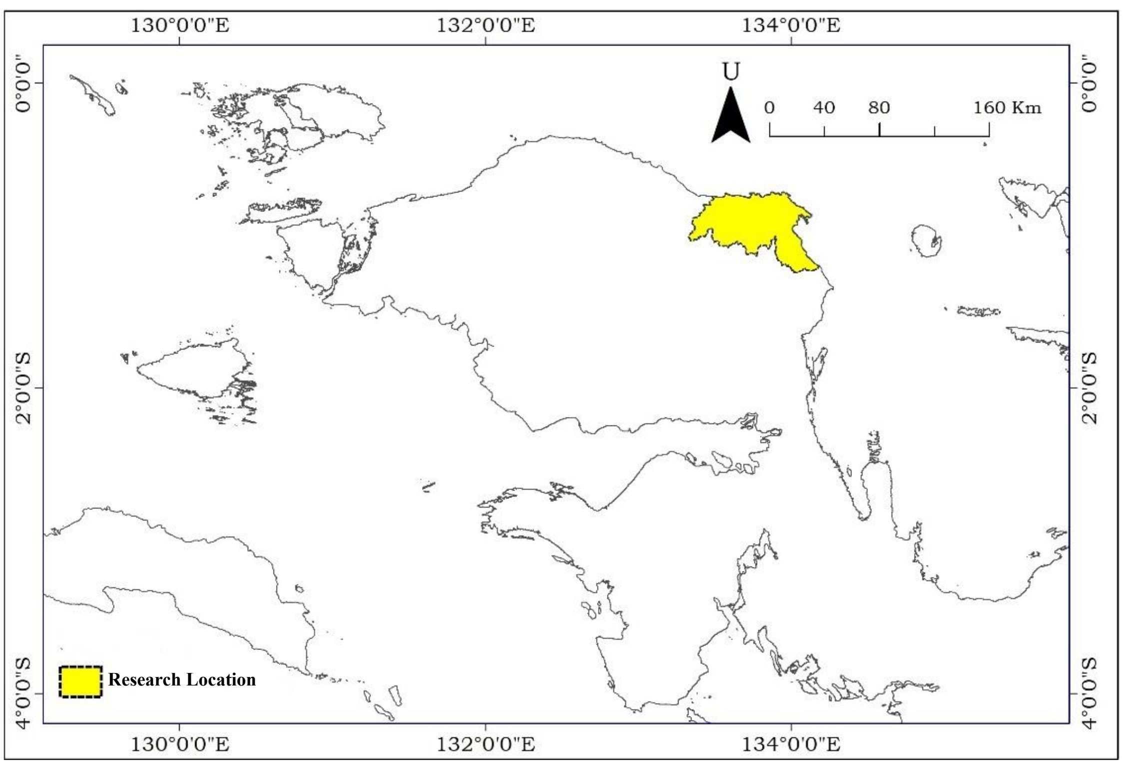


Figure 1. Research location for *LS* factor analysis in Manokwari Regency.

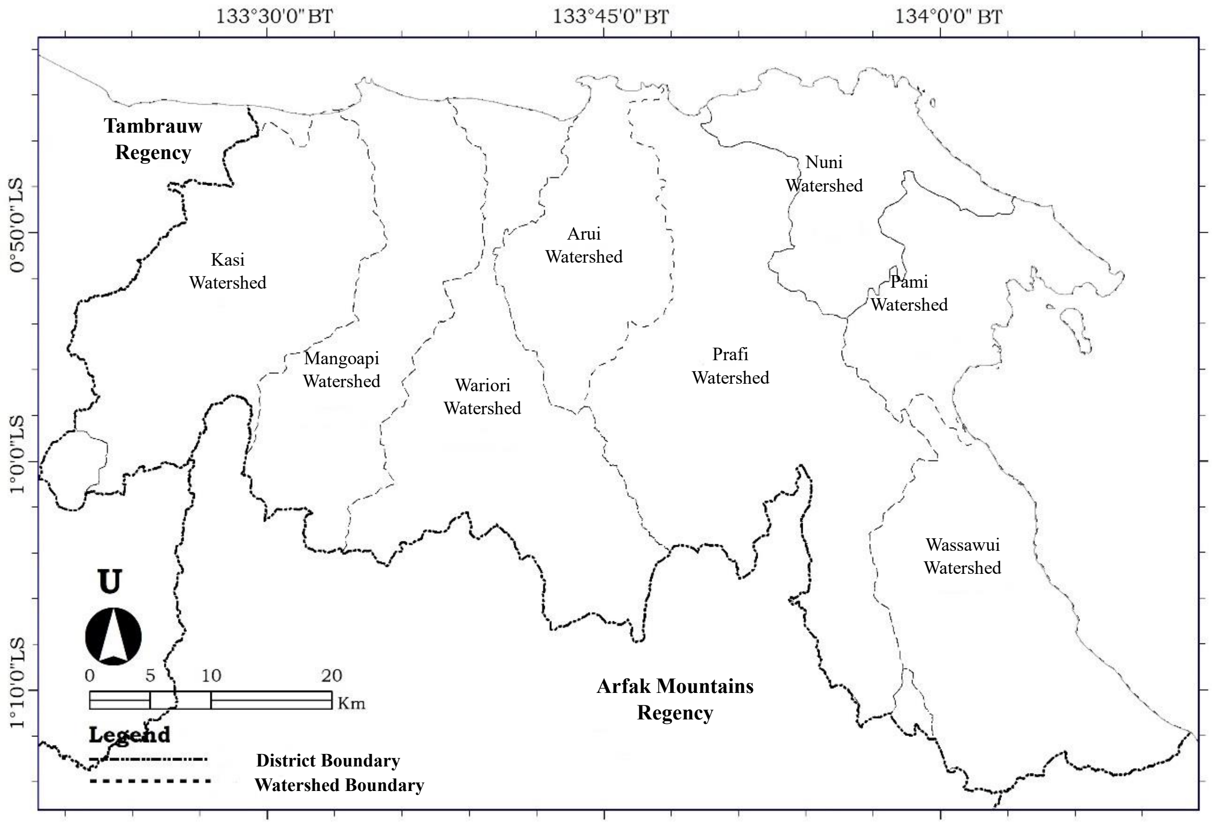


Figure 2. Distribution of watersheds in Manokwari Regency

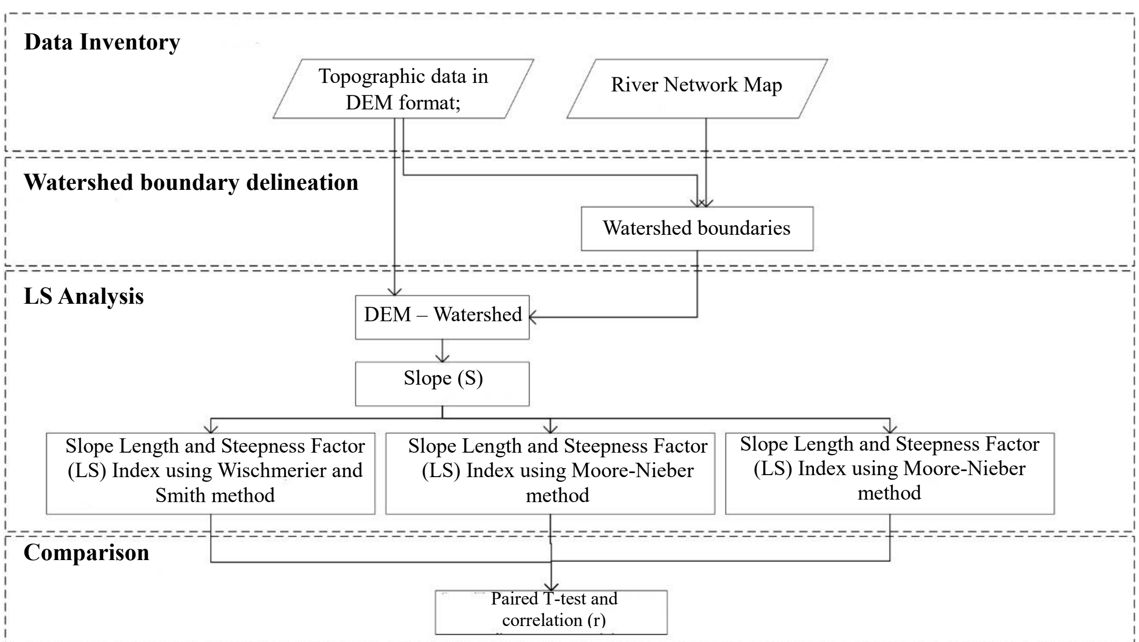


Figure 3. Research flowchart

3. Slope Length and Steepness Factor (*LS*) Index Analysis

This stage aims to calculate the slope length and steepness factor (*LS*) index using 3 (three) methods, namely Wischmeier-Smith, Moore-Nieber, and Desmet-Govers. Wischmeier-Smith calculates LS using the following equation (Wischmeier & Smith, 1978):

$$LS = \left(\frac{\lambda}{22{,}13}\right)^{m} x(65.4sin^2\beta + 4.5sin\beta + 0.0654) \tag{1}$$

where *LS* is the slope length and steepness factor index; λ is the slope length (feet), β is the slope angle (degrees); m = 0.5 if β > 5%, m = 0.4 if 3% < β < 5%, m = 0.3 if 1% < β < 3%, and m = 0.2 if β < 1%.

Moore-Nieber calculates *LS* using the following equation (I. D. Moore & Nieber, 1989):

$$LS = \left(\frac{\lambda}{22.13}\right)^{0,4} x \left(\frac{\sin\beta}{0.0896}\right)^{1,3} \tag{2}$$

where LS is the slope length and steepness factor index; λ is the slope length (m), β is the slope angle (degrees).

Desmet - Govers calculates LS using the following equations (Desmet & Govers, 1996):

$$L_{(i,j)} = \frac{\left(A_{(i,j)}+D^2\right)^{m+1} - A_{(i,j)}^{m+1}}{x^m\, D^{m+2}\, 22.13^m} \tag{3}$$

$$S = -1{,}5 + \frac{17}{\left(1+e^{(2.3-6{,}1\sin\beta}\right)} \tag{4}$$

$$m = \frac{\beta}{\beta+1} \tag{5}$$

where *L* is the slope length factor index; *S* is the slope steepness factor index; λ is the slope length; *A* is the cell (pixel) data in raster format (m²); *D* is the pixel size (raster data resolution) (m); *m* is the power factor of the slope length and steepness index; *x* is the correction coefficient; and β is the slope angle (degrees).

4. Comparison of Slope Length and Steepness Factor (LS) Indices

This stage aims to compare the *LS* indices obtained using the Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods. The comparison is performed using a paired T-test and correlation test. The T-test is conducted on each LS pixel and calculated using the following equation (Machiwal & Jha, 2012; Nuryadi *et al.*, 2017):

$$ts = \frac{|\overline{x_2} - \overline{x_1}|}{\sqrt{\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{n_1+n_2-2}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \tag{6}$$

where *ts* is the T-test value, s_1 is the variance of group 1, s_2 is the variance of group 2, n_1 is the number of data in group 1, and n_2 is the number of data in group 2.

The T-test is conducted at a significance level of 5% or α = 0.05. If the T-test value ($T_{calculated}$) > critical value (T_{table}), there is a significant difference in LS values between Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods. If the T-test value ($T_{calculated}$) < critical value (T_{table}), there is no significant difference in *LS* values between Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods.

The correlation test (*r*) is also conducted on each LS pixel and calculated using the following equation:

$$r = \frac{\sum_{i=1}^{n}(yi-\bar{y})(xi-\bar{x})}{\sqrt{\sum_{i=1}^{n}(yi-\bar{y})^2}\sqrt{\sum_{i=1}^{n}(xi-\bar{x})^2}} \tag{7}$$

where y_i is the *LS* value of method 1 at the *i*-th pixel; $\bar{y}$ is the average *LS* value of method 1; x_i is the *LS* value of method 2 at the *i*-th pixel; $\bar{x}$ is the average *LS* value of method 2; and *n* is the number of pixels. The degree of correlation was classified into three groups based on (Jackson, 2009), namely strong for *r* value between 0.70 – 1.00, moderate for r value of 0.30 – 0.69, and Weak correlation for r value of 0.00 – 0.29.

3. RESULTS AND DISCUSSION

Based on the processing of topographic data in the DEM format with an 8-meter resolution released by the Geospatial Information Agency (BIG) in 2018, the watersheds in Manokwari Regency have slopes ranging from 0° to 81.5°. The slopes of the watersheds in Manokwari Regency are presented in Figure 4 and Table 2.

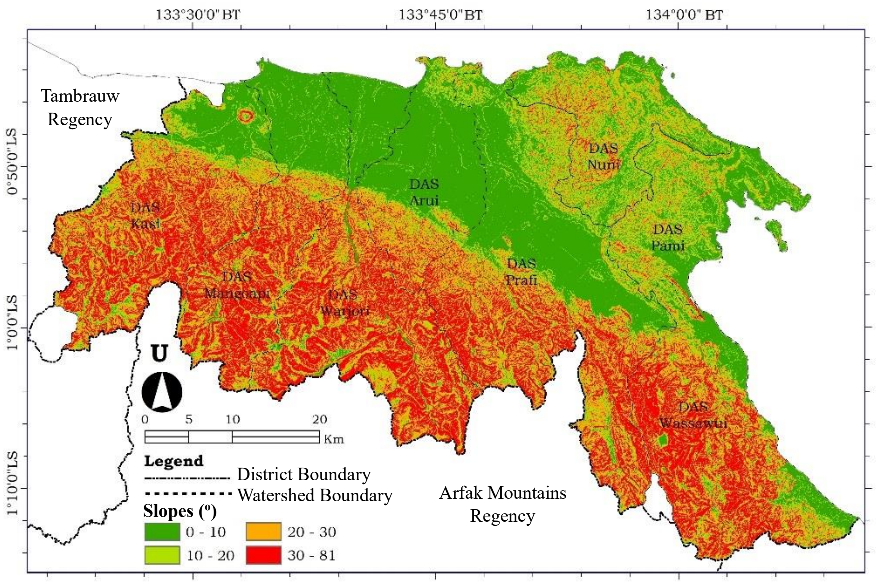
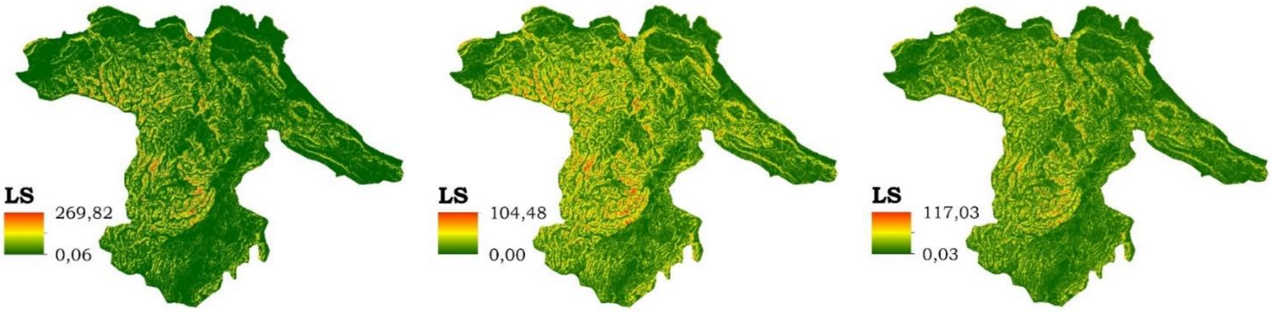


Figure 4. Slopes of Watersheds in Manokwari Regency.

Table 2. Average slopes of watersheds in Manokwari Regency

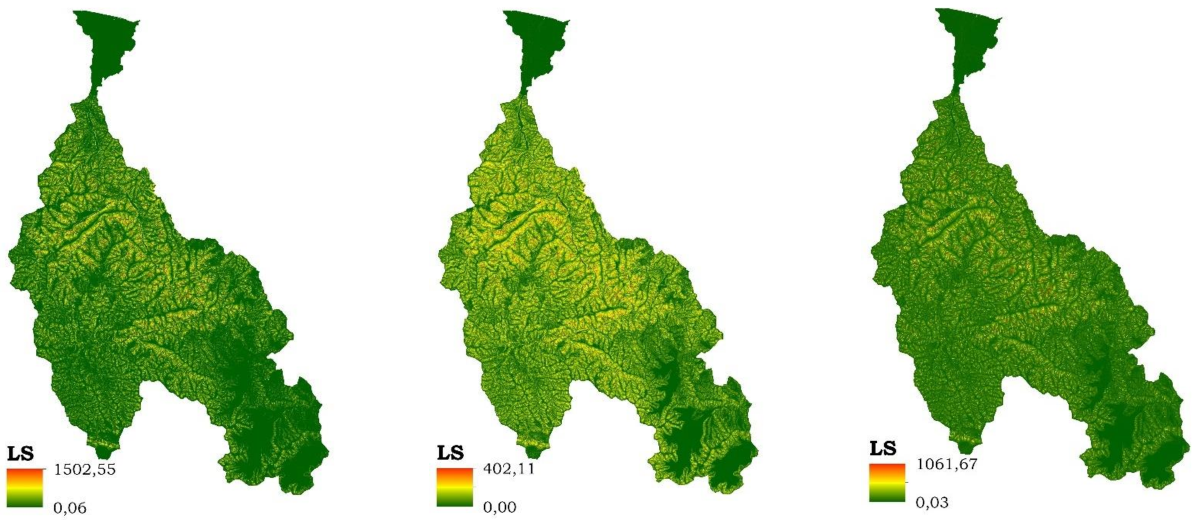
No	Watershed	Area (km^2)	Average Slope (°)
1	Nuni	231	14.12
2	Wariori	1635	23.69
3	Mangoapi	374	21.19
4	Prafi	676	18.79
5	Wassawui	500	24.39
6	Kasi	980	23.04
7	Arui	232	10.21
8	Pami	216	11.99

In general, the Wischmeier-Smith method provides higher *LS* values compared to the Moore-Nieber and Desmet-Govers methods. Meanwhile, the Desmet-Gover method provides the lowest average *LS* values compared to the Wischmeier-Smith and Moore-Nieber methods. The results of the Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods in calculating *LS* for watersheds in Manokwari Regency, West Papua Province, are presented in Figures 5 to 12. The comparison of *LS* values based on several statistical parameters is presented in Figure 13. In overall, the LS values resulting from the Wischmeier-Smith method analysis are higher compared to the Moore-Nieber and Desmet-Govers methods, and the LS values from the Desmet-Govers method analysis are the lowest compared to the Wischmeier-Smith and Moore-Nieber methods. This is because the Wischmeier-Smith and Moore-Nieber methods consider flow accumulation in calculating LS, resulting in higher LS values in areas close to mountainous regions (Ansari & Tayfur, 2023). This study's results are relevant to the research conducted by Hrabalíková & Janeček (2017), which compared the Wischmeier-Smith, Desmet-Govers, McCool, and Moore-Wilson methods in analyzing *LS* on a laboratory scale. The results showed that the *LS* values from the Wischmeier-Smith method analysis were higher compared to the Desmet-Govers, McCool, and Moore-Wilson methods (Hrabalíková & Janeček, 2017). Furthermore,



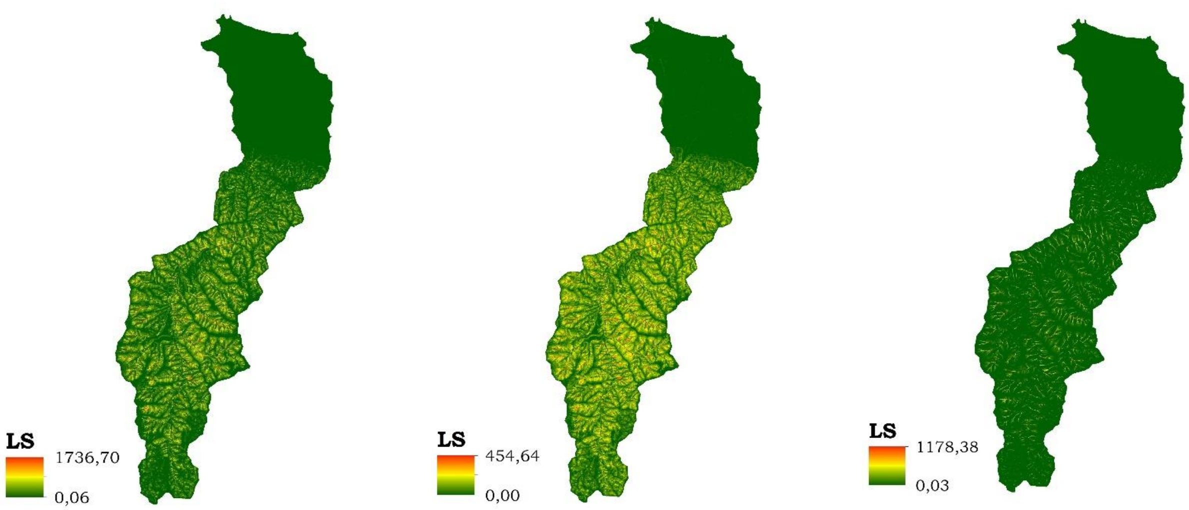
(a) Wischmeier-Smith (b) Moore-Nieber (c) Desmet-Govers

Figure 5. LS values for Nuni Watershed; (a) method, (b) method, (c) method



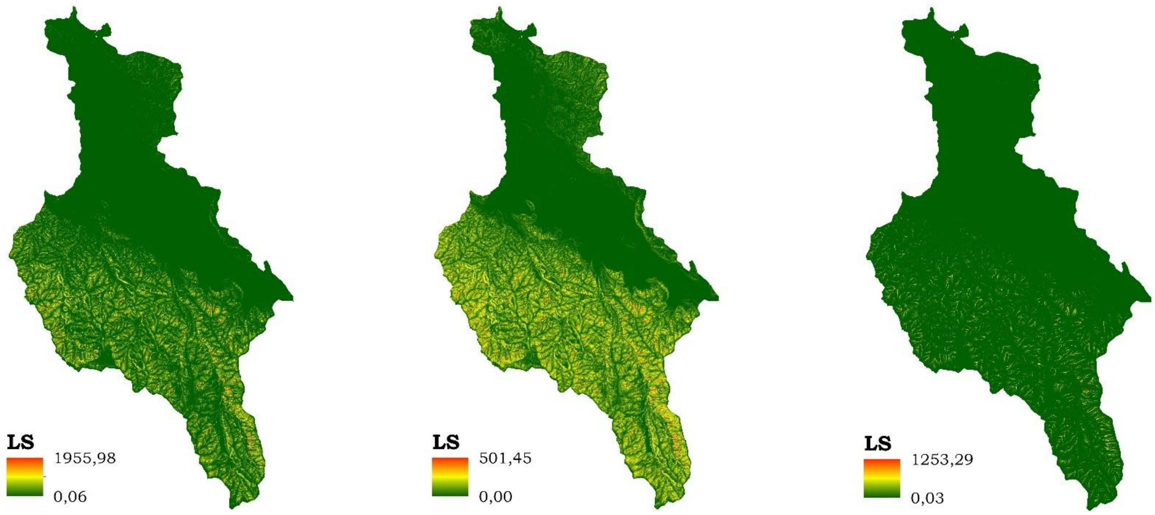
(a) Wischmeier-Smith (b) Moore-Nieber (c) Desmet-Govers

Figure 6. LS values for Wariori Watershed



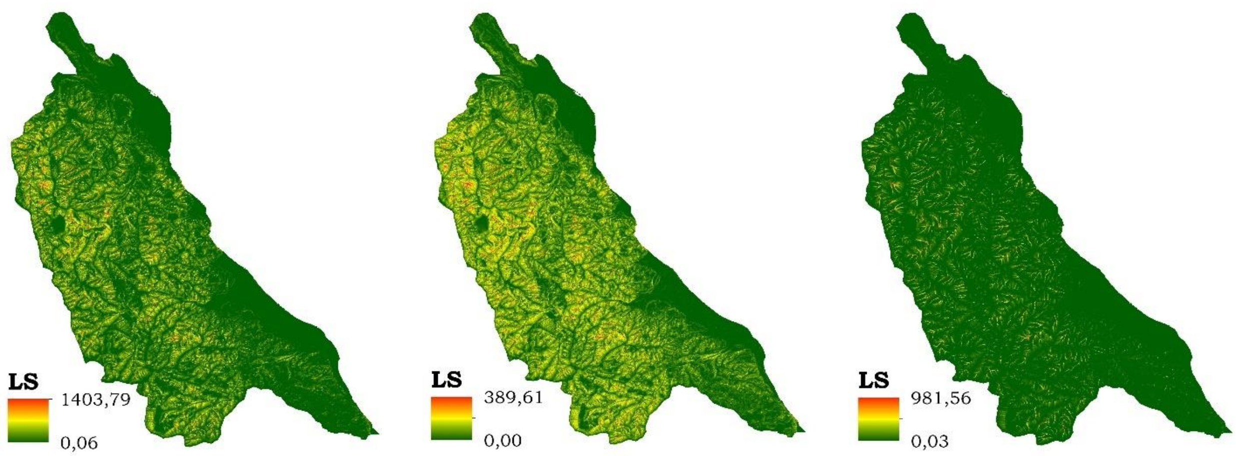
(a) Wischmeier-Smith (b) Moore-Nieber (c) Desmet-Govers

Figure 7. LS values for Mangoapi Watershed



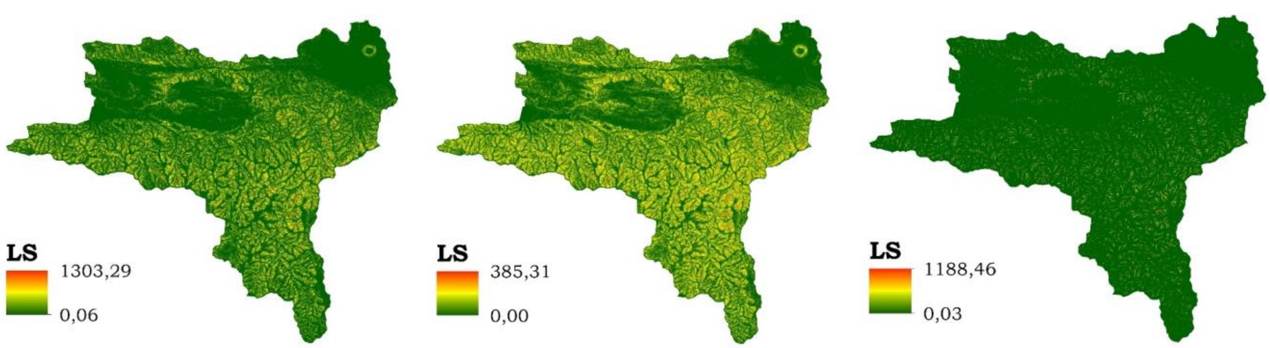
(a) Wischmeier-Smith (b) Moore-Nieber (c) Desmet-Govers

Figure 8. LS values for Prafi Watershed



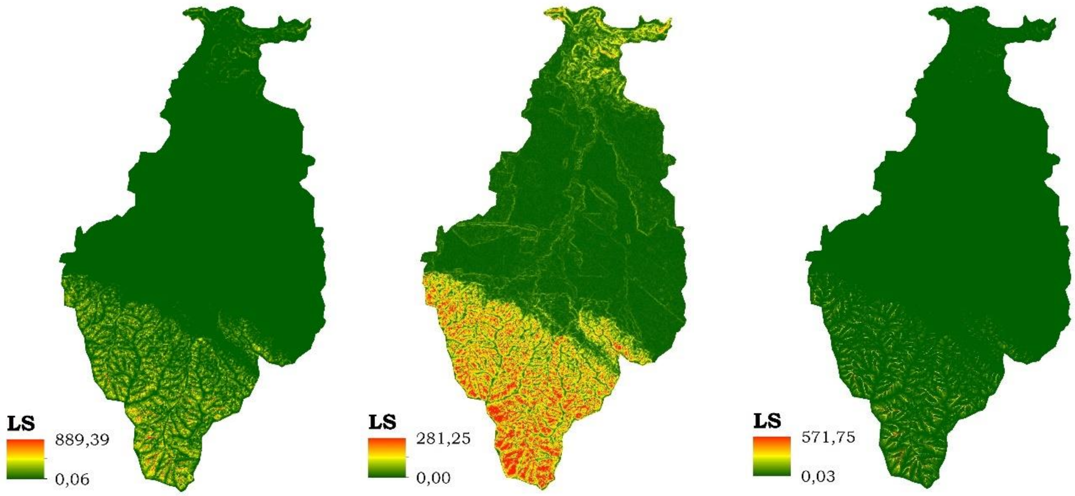
(a) Wischmeier-Smith (b) Moore-Nieber (c) Desmet-Govers

Figure 9. LS values for Wassawui Watershed



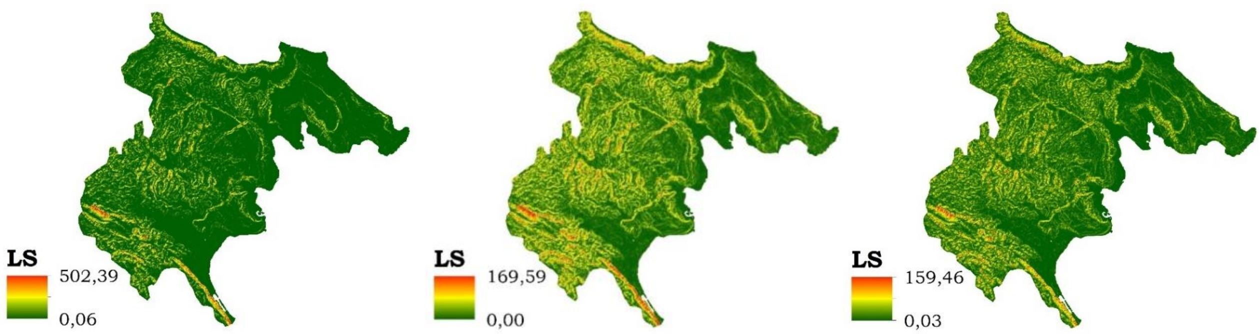
(a) Wischmeier-Smith (b) Moore-Nieber (c) Desmet-Govers

Figure 10. LS values for Kasi Watershed



(a) Wischmeier-Smith (b) Moore-Nieber (c) Desmet-Govers

Figure 11. LS values for Arui Watershed



(a) Wischmeier-Smith (b) Moore-Nieber (c) Desmet-Govers

Figure 12. LS values for Pami Watershed

Badora & Wawer (2023) compared the Moore-Nieber, Desmet-Govers, and Boehner-Selige methods in analyzing *LS* in the Bystra Watershed, Poland. The results showed that the LS values from the Desmet-Govers method analysis were lower compared to the Moore-Nieber method (Badora & Wawer, 2023). The comparison of *LS* values from the Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods for several watersheds in Manokwari Regency is presented in Figures 13 to 20.

Based on the T-test results, the *LS* values from the Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods show significant differences. This is relevant to the research results of Ansari & Tayfur (2023) and Suhua *et al.* (2013), which indicate that *LS* values from various methods have significant differences in large areas due to very diverse topographic conditions. However, *LS* values tend to have insignificant differences in smaller areas (Hrabalíková & Janeček, 2017; Garcia Rodriguez & Gimenez Suarez, 2012) due to less diverse topographic conditions. The T-test results for *LS* values from the Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods for several watersheds in Manokwari Regency are presented in Table 2.

Although the *LS* values obtained using the Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods are significantly different, they have a strong correlation with an average correlation value (r) of 0.92. The correlation test results for *LS* values using the Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods in several watersheds in Manokwari Regency are presented in Table 3.

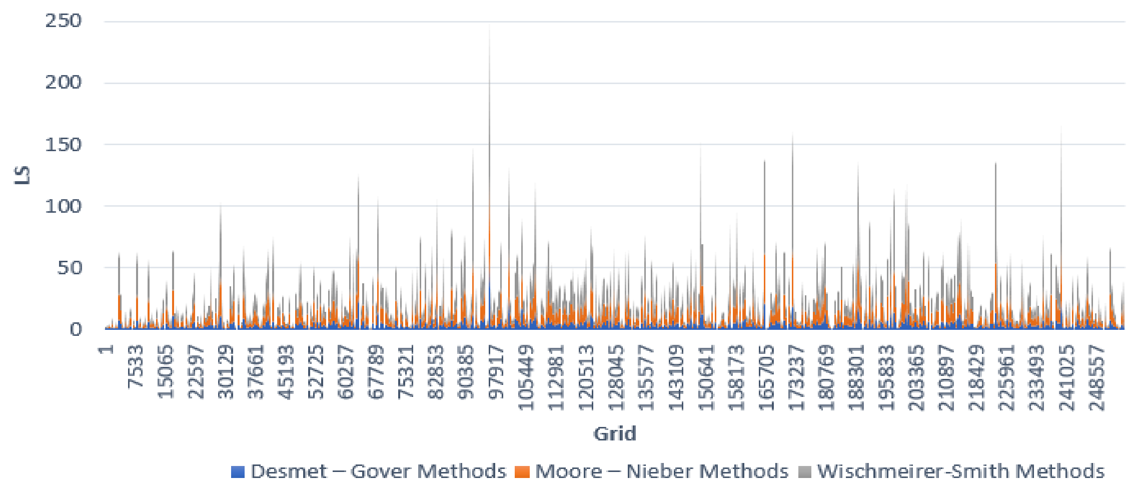


Figure 14. Comparison of *LS* values for Nuni Watershed

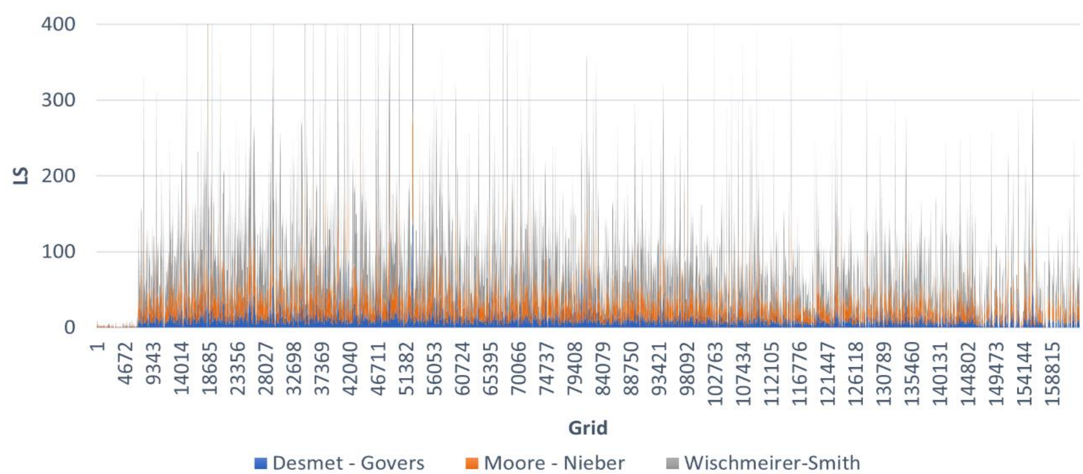


Figure 15. Comparison of *LS* values for Wariori Watershed

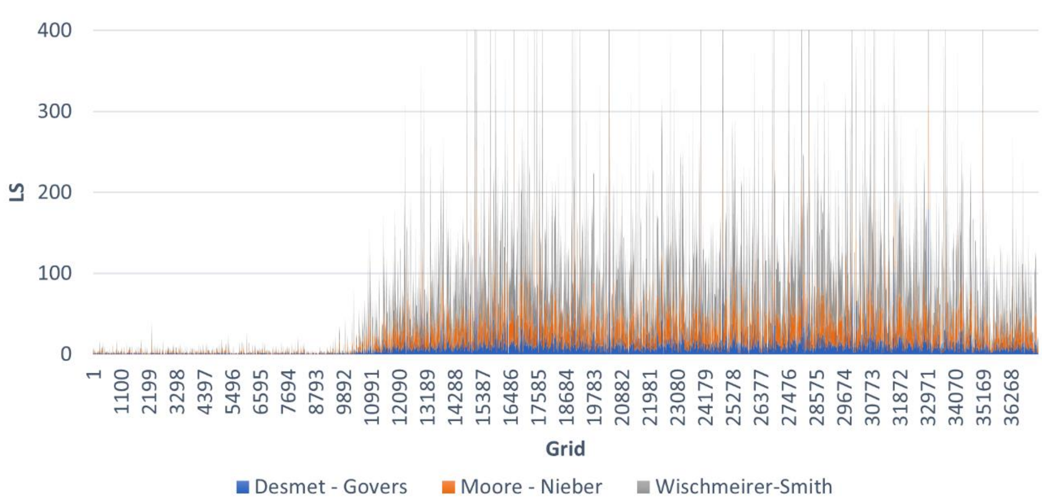


Figure 16. Comparison of *LS* values for Mangoapi Watershed

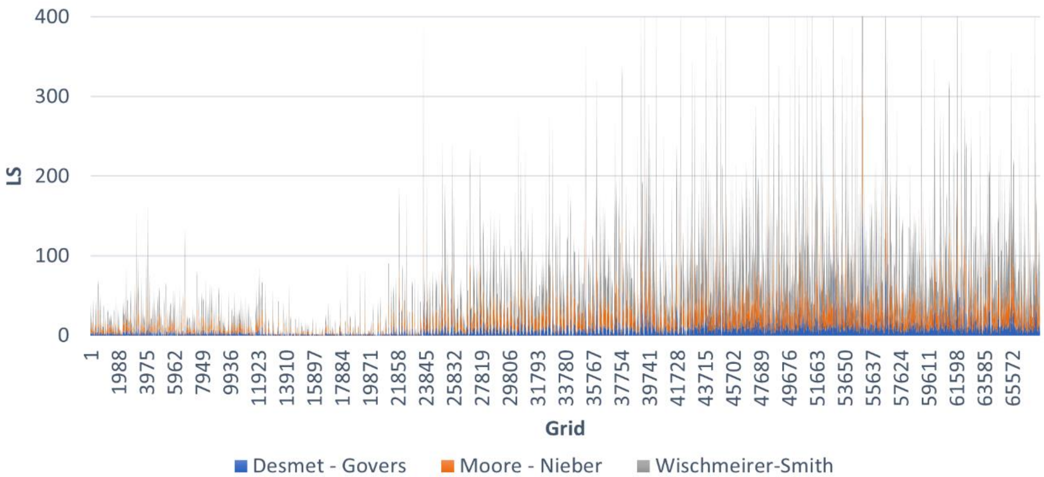


Figure 17. Comparison of LS values for Prafi Watershed

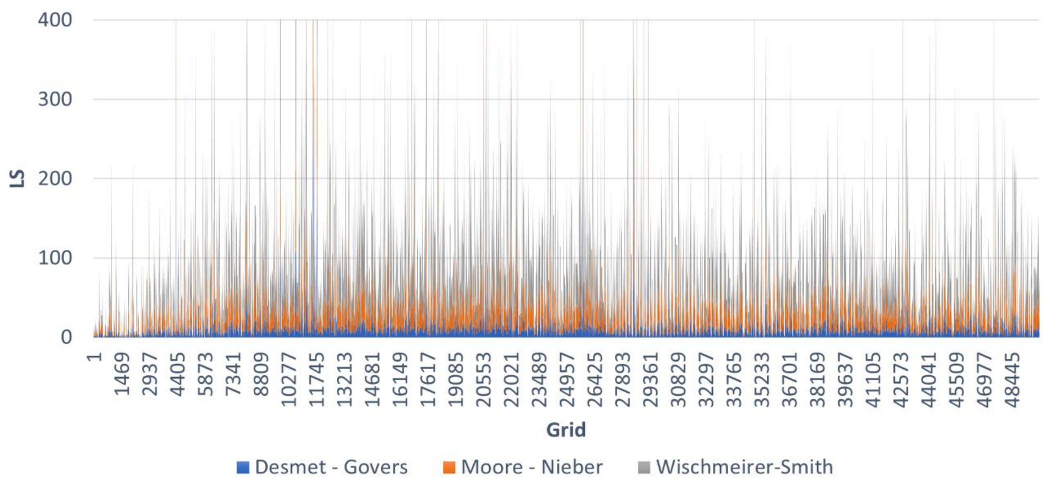


Figure 18. Comparison of LS values for Wassawui Watershed

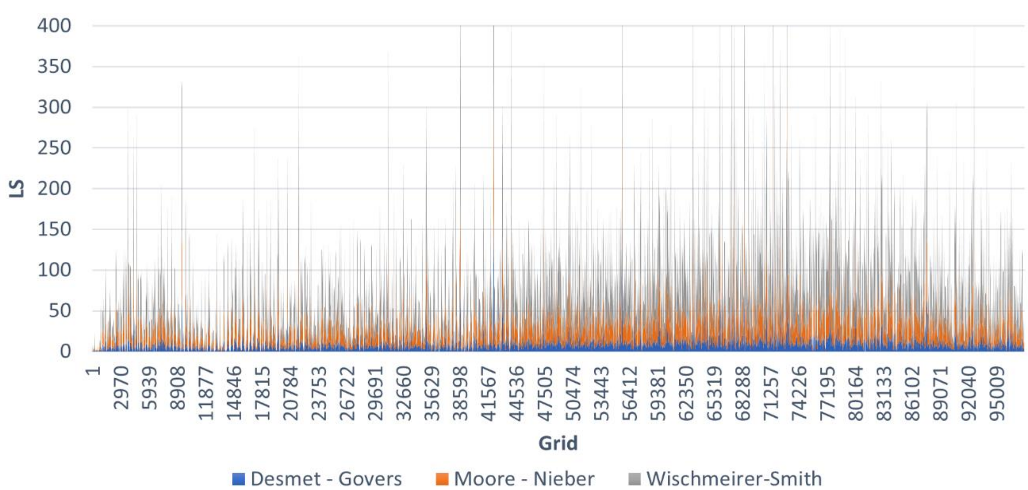


Figure 19. Comparison of LS values for Kasi Watershed

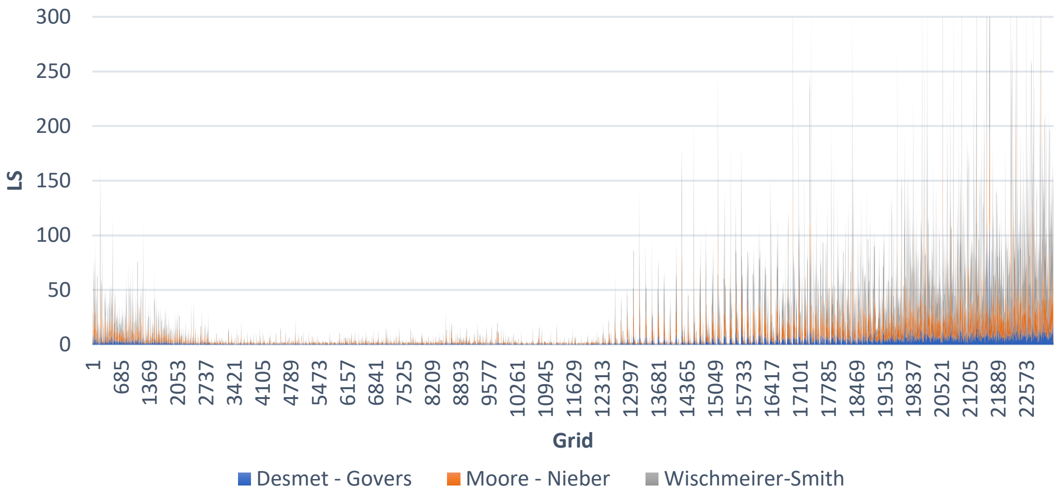


Figure 20. Comparison of LS values for Arui Watershed

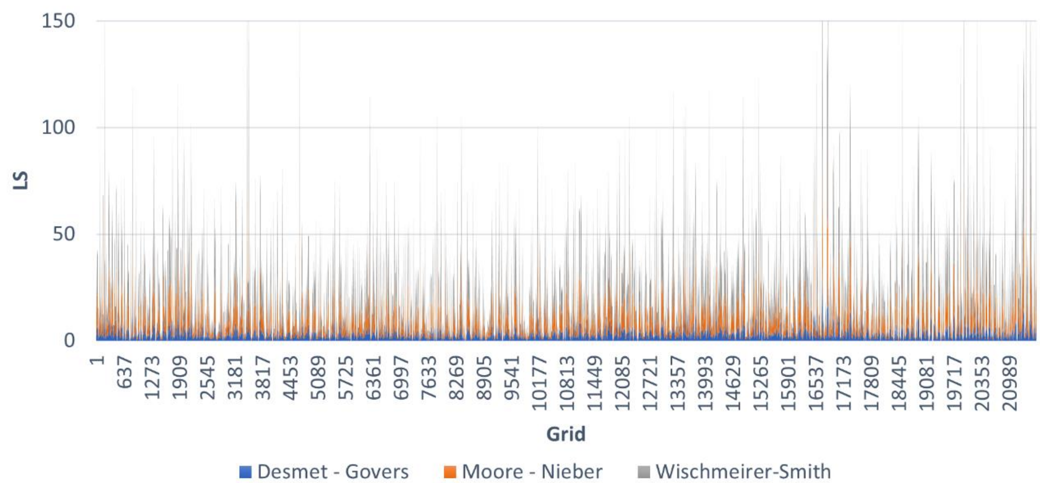


Figure 21. Comparison of LS values for Pami Watershed

Table 2. Paired T-test results for *LS* values in several watersheds in Manokwari Regency

No	Watershed	Method					
		Desmet-Govers vs. Moore-Nieber		Desmet-Govers vs. Wischmeier-Smith		Moore-Nieber vs. Wischmeier-Smith	
		$T_{calculated}$	T_{table}	$T_{calculated}$	T_{table}	$T_{calculated}$	T_{table}
1	Nuni	546.01	1.64	381.24	1.64	248.48	1.64
2	Wariori	490.65	1.64	396.17	1.64	289.48	1.64
3	Mangoapi	900.45	1.64	813.28	1.64	604.39	1.64
4	Prafi	808.20	1.64	638.21	1.64	476.54	1.64
5	Wassawui	865.33	1.64	695.07	1.64	509.48	1.64
6	Kasi	1.300.02	1.64	1.006.4	1.64	742.04	1.64
7	Arui	630.46	1.64	505.18	1.64	362.88	1.64
8	Pami	939.48	1.64	640.06	1.64	380.78	1.64
	Average	740.08	1.64	581.31	1.64	451.76	1.64
	Significance	Significantly different		Significantly different		Significantly different	

Table 4. Correlation test results for *LS* values in several watersheds in Manokwari Regency

No	Watershed	Method		
		Desmet-Govers vs. Moore-Nieber	Desmet-Govers vs. Wischmeier-Smith	Moore-Nieber vs. Wischmeier-Smith
1	Nuni	0.94	0.93	0.98
2	Wariori	0.87	0.89	0.98
3	Mangoapi	0.86	0.89	0.98
4	Prafi	0.87	0.89	0.98
5	Wassawui	0.86	0.89	0.98
6	Kasi	0.87	0.88	0.99
7	Arui	0.88	0.91	0.98
8	Pami	0.95	0.94	0.98
	Average	0.89	0.90	0.98
	Relationship strength	Strong	Strong	Strong

Based on several studies, some factors influencing the differences in LS values across different methods include watershed area (Ansari & Tayfur, 2023; Suhua *et al.*, 2013; Hrabalíková & Janeček, 2017a) and DEM data pixel size (Hrabalíková & Janeček, 2017a; Bircher *et al.*, 2019; Yao *et al.*, 2010; Michalopoulou *et al.*, 2022).

4. CONCLUSION

The Wischmeier-Smith method provides higher LS values compared to the Moore-Nieber and Desmet-Govers methods in estimating LS values for several watersheds in Manokwari Regency. The Desmet-Gover method provides lower LS values compared to the Wischmeier-Smith and Moore-Nieber methods. Furthermore, the LS values obtained using the Wischmeier-Smith, Moore-Nieber, and Desmet-Govers methods show significant differences in estimating LS for several watersheds in Manokwari Regency.

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