Spatial pattern of sediment transport for analysis of precipitation direction and magnitude in the upper Lematang river sub-basin

Sarino1, Agus Lestari Yuono1, Putranto Dinar DA2*

1 Civil Engineering and Planning Study Program, Faculty of Engineering, University of Sriwijaya. Jl. Raya Inderalaya, Km. 32, Inderalaya, Ogan Ilir Regency, South Sumatera Province, Indonesia
2* Civil Engineering Post Graduate Study Program, Faculty of Engineering, University of Sriwijaya. Jl. R. Soeprapto, Bukit Besar, Palembang City, South Sumatera Province, Indonesia.

Abstract. The high level of erosion that occur in Musi river basin has improved a tremendous impact on sedimentation in downstream areas and has resulted in many infrastructure of water is disturbed, such as silting of irrigation channels, siltation of rivers which disrupt the flow of transport stream and increasing the risk of flooding, high sedimentation in the port basin, low quality of water and the rising costs of water treatment. This study utilizes techniques terrain models Digital (Digital Elevation Model/DEM) to analysis the spatial distribution of the potential for erosion and sources of sedimentation, as well as the direction of the flow of sediment into channels as well as its relationship with outlet in branching river as the supplies to be sediment to the river flow. The method used in this study using a spatial model analysis with the help of GIS in analysing and presenting the level of erosion and deposition by utilizing modelling slope and kinetic energy of rainfall to estimate the index erosivity and distribution pattern of sediment into the river channel. This research was conducted at the upper Lematang river sub basin with area 412,638 Ha, which are classified into 11 sub-chatments with the highest altitude is 3.159 m above sea level (Dempo Valley) and the lowest is 126 m above sea level (Talang tinggi Valley). Analytical results have been tested by taking a fine sediment sampling in each sub-watershed in the analysis and is taken along the channel network and compare the observed patterns with the results predicted by the model analysis of soil erosion. Overall, erosion by high intensity tends to occur in the relationship between the different vegetation coverage, the barren land and open land used for farms and land used for mining. Approximately 45-65.5% slope bad condition because the vegetation has been open, so it can be seen the amount of erosion in the area is 2.139 ton/ha/year, at the sloping is 1.8239 ton/ha/year.

1. Introduction

The high erosion in the Musi River Basin from year to year is increasing. Some sub-basins, such as the Ogan river sub basin, Lematang River sub Basin, Komering River sub Basin, are the biggest contributors to the erosion and sedimentation processes in the Musi river basin [1]. The negative effects of soil erosion are the high sedimentation at the mouth of the Musi river and the occurrence of dwelling time
at the Bom Baru port in Palembang [2]. In addition to its role in river flow sediment load transportation, it also influences the erosion of river banks, thereby increasing the amount of sediment load carried. The eroded material or sedimentation material from the hill slope is partially deposited back in the slope system and some is flowed into the river, according to the comparison of the existing slope [3]. Thus the amount of material loss from the existing slope system will result in a spatial pattern of erosion and sedimentation.

2. Methodology

2.1. The process of erosion

Erosion is a process or event of loss of topsoil, either caused by movement of water or wind. Erosion is three sequential processes, namely detachment, transportation, and deposition of soil materials caused by erosion [4].

In humid tropical regions such as Indonesia, water is the main cause of erosion, whereas for hot, dry areas wind is the main cause. Erosion is the flaking of top soil particles or rocks by natural factors such as water and wind, and is exacerbated by human activity. The main factors of soil erosion that remove soil particles due to rain water are two main processes, namely the release caused by rain falling on the ground and runoff [5].

2.1.1. Erosivity

Erosivity is a characteristic of rainfall. Rain with low intensity or rarely causes erosion, but heavy rainfall with long and short periods can cause large runoff and soil loss. The nature of rainfall that affects erosivity is seen as the kinetic energy of raindrops that hit the ground surface. Rainfall that falls directly or indirectly can erode the soil surface slowly with increasing time and the accumulation of rainfall intensity will cause erosion [6].

Rain kinetic energy (E, in Joule / m²) is influenced by the average annual rainfall (R) and rainfall intensity (I), can be derived from the equation, Smith and Weischmeier in Browsdoski [3]

\[ E = 210.3 + 89 \log_{10} I \] (1)

To get rain kinetic energy with rainfall intensity for 30 minutes (\(I_{30}\)), the above equation becomes:

\[ EI_{30} = E x (I_{30} x 10^{-2}) \] (2)

\( E_{I_{30}} \), Rain erosivity index; E, Total rain kinetic energy (Joule / m²); \( I_{30} \), max rain intensity for 30 minutes.

2.1.2. Erodibility

To obtain a flow strength model (sediment transport), it is calculated by estimating mass conservation to simulate soil erosion and sedimentation. The average change in soil loss E (tons / ha / year) is predicted through the RUSLE equation approach [4]. The RUSLE (Revised Universal Soil Loss Equation) model is a development of the USLE model which is an empirical model that predicts surface erosion and grooves associated with surface flow.

\[ E = R.K.L.S.C.P \] (3)

where E, the rate of soil erosion (tons / ha / year); R, Rain Erosion Factor; K, soil erodibility factor; LS, Slope length and slope (steepness of slope); C, land management factors (coefficient of infiltration of vegetation cover); P, Index of land management or soil conservation measures.

Factors R, K, C, and P have been determined empirically. The LS factor, is calculated to predict the strength / erosivity of the Run-off and is expressed as the ratio of soil loss that is affected by the slope and length of the slope. For soil loss in standard conditions, at a slope of about 5° (9%) with a slope length of about 22.13 meters [7], use the following equation
Geomatics International Conference 2019

LS = (λ/22,13)t (65,4 Sin^2β + 4,56 Sin β + 0,0654)

where λ is the length of the slope in meters (horizontal projection of the slope length in meters), β is the slope angle (degrees), and t is the length exponent depending on the steepness of the slope, with a value of 0.5 for slopes exceeding 5%, 0.4 for the slope averages between 3-5%, and 0.3 for slopes less than 3%. The use of these equations, because of the standard formula commonly used, has failed to take into account the complexity of the topography, in areas that are not sloping, because no contribution is found in the delivery of sediments. For example [8], it is argued that the use of sediment delivery ratios formulated in USLE, does not take into account sediment deposition, while sediment deposition often occurs on hills.

The Unit Stream Power Erosion and Deposition Model or USPED [9], predicts the spatial distribution of erosion and deposition rates for stable flow conditions related to conditions caused by rainfall. In this study the erosion and deposition maps in the USPED model will be tested on the upper Lemang river sub Basin, with the aim of obtaining indicators to see which areas of land are most likely to be suppliers of fine sediment to the canal network, and to obtain a quantitative index of sediment supply to the channel network.

The USPED model assumes that sediment transport on slopes has a limited capacity, which means that the level of sediment transport is determined by the erosion strength of running water, and is not limited by the supply of transported soil particles. Thus it is assumed that the level of sediment transport is obtained from equation [9] :

\[ q_s = K_t q_m s^n b \]

where b is the local surface slope (degree), q is the rate of water flow per unit (m² / sec), Kt is the coefficient of soil transportability (depending on soil properties and vegetation cover), and m and n are constants depending on the type of flow and soil properties. Equation (5) gives sediment fluctuations (volume per unit width, m² / s) in the direction of the maximum slope gradient.

The exponent value of n (slope / steepness exponent) varies and is analysed according to the shape of the slope, the type of land cover, and also the erosion process. Thus, various exponent values have been determined for different climates, but the standard for the United States [8] is around 0.3-1.0 for high rainfall and around 0.7 and 1.7-2.0 respectively for detachment and transportation of soil particles with surface flow (surface erosion). Kirkby [9] quoted by Morgan [9] showed that the length of the slope of the exponent m ranged from 0.3 to 0.7 for surface flow and rose to between 1.0 and 2.0 in the case of rapid flow. The value used in the USPED model for n (1.3) has been used to be the most suitable exponent for use in the RUSLE equation by deriving the theory of flow strength [9]. For surface flow, the constants m and n are set for m = 1.6 and n = 1.3.

Steady-state water flow can be expressed as a function of upslope contribution per unit contour width A (m² / m) :

\[ q = A_i \]

where i [m / s] is the average rainfall intensity. Thus equation 5 can be restated as :

\[ q_s = K_t (A_i)^m s^n b \]

This formulation is limited because no experimental work has yet been done to assign values to the Kt parameter [9]. If it is assumed that Kt ~ KCP and im ~ R, then the relative magnitude of sediment fluctuations can be estimated from the form of the USLE equation as:

\[ q_s = R.K.C.P.A^n. s^n b \]

where m and n constants have values 1.6 and 1.3, respectively, for real erosion and 1 for surface erosion [8]. The equation is a law of erosion flow strength that combines values obtained empirically from USLE parameters. As a comparison for RUSLE (equation 3), it can be seen that LS ~ Am sin β. Because the USPED equation is a hybrid between RUSLE and the flow strength based on the transport model. The results of the USPED model present the relative direction of average soil erosion and the level of
deposition of soil loss values which are rather specific and expressed in tons / hectare / year. This issue is an issue that needs to be considered by stakeholders to make computational comparisons in estimating the magnitude of erosion in sub-watershed areas.

The average value of soil erosion or deposition (ED) is given by two dimensions (horizontal plane) differences in sediment fluctuations that express conservation of mass:

$$\text{ED} = \text{div} (q_s) = \frac{d (q_s \cos \alpha)}{dx} + \frac{d (q_s \sin \alpha)}{dy}$$

where $\alpha$ is an aspect of the terrain surface (the direction of the gradient of the maximum slope in the horizontal plane in degrees). Sediment transport models (equation 8) combined with mass conservation (equation 9) illustrate the average spatial pattern of overland flow (and thus the upstream area contributes, equation 6) while the slope gradient and topographic control aspects contribute to the distribution of soil erosion and deposition.

Equations for sediment fluctuation (equation 8) and addition of fluctuation sediments (equation 9) are used to calculate the topographic effect on the slope and direction of transport and patterns resulting from erosion and deposition. The erosion and deposition map revealed in this study, namely the upper Lematang sub basin by applying the USPED model is intended to use this map as a visual indicator spatially to predict which areas are most likely to be suppliers of fine sediment to the canal network, and to obtain a quantitative index of supply sediment to the channel network.

3. Implementation of the model

Administratively the research area is located in Lahat district, South Sumatra Province. West, south, and east to the border of the Barisan valley mountains with its peak is Dempo mountain (3,159 m), Megang mountain (1,616 m), Rajamendara valley (2,226 m), Broken mountain (2,617 m), Balai valley (2,284 m), Batukuning valley (2,350 m), Jambul valley (1,856 m), Isau-isau mountain (1,431 m), and Large valley (733 m). The northern part with Gumai valley, Padang Sereting Valley (175 m), Batu Valley (132 m), Talang Tinggi valley (126 m), and Lanap valley (426 m). The upper area of the Lematang river sub-basin is 412,638 Ha and is part of the Lematang river sub-basin with an area of 881,442.49 Ha. Elevation, soil type, land cover, and hydrographic data of the study area were obtained from a number of sources, such as the Geospatial Information Agency (BIG) for height data, land use and soil data, and BMKG for rainfall data.

3.1. Topographic index (direction factor and slope)

The topographic index is calculated using GIS assistance, through DEM modelling or Digital Elevation Model using 10 m pixel size from SRTM data obtained from the Geospatial Information Agency (BIG). The analysis was carried out based on height contour data to obtain the slope, slope length, and div. X direction and div Y direction from the slope.

3.2. Rain Intensity ($I_{30}$)

The amount of rainfall ($R$) is a function of increasing kinetic energy (KE), soil susceptibility index (Kd) and percentage of rainfall interception (INT). Annual kinetic energy can be calculated from a rainfall station graph using an equation or alternative estimated from rainfall data using an empirical equation. To calculate the amount of kinetic energy acting in the area, the intensity of 30 minutes of rainfall ($I_{30}$) is used. From the calculation of rainfall intensity with a return period of 5 years, it is determined as the result of an analysis that approaches the actual rainfall intensity conditions in the field. Rainfall data uses daily rainfall data for ten years (2007-2017) for three observation stations in the study location, namely PTPN VII (Pagar Alam), Pagar Alam Police Station, and Jarai Station (North Pagar Alam). Data from the three locations of the observation station are then analyzed to obtain spatial distribution with Tiesen polygons for thirty minutes of rain intensity ($I_{30}$) every month with a return period of 5 years.
Table 1. Monthly 30 minutes ($I_{30}$) rainfall intensity, three observation stations in the upper Lematang sub-Basin research area.

| Station | Rain Intensity ($I_{30}$) |
|---------|---------------------------|
|         | Jan. | Feb. | Marc | Apr. | May. | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
| PTPN    | 7.948 | 9.209 | 8.902 | 10.952 | 8.436 | 7.212 | 9.774 | 8.205 | 8.642 | 8.635 | 12.376 | 8.996 |
| Polres  | 8.043 | 8.891 | 8.459 | 7.905 | 9.460 | 7.512 | 7.198 | 6.308 | 6.154 | 9.766 | 10.263 | 9.016 |
| Jarai   | 7.948 | 9.209 | 8.902 | 10.952 | 8.436 | 7.212 | 9.774 | 8.205 | 8.642 | 8.635 | 12.376 | 8.996 |

3.3. Erodibility factor ($K$)
Soil erodibility (soil resistance) can be determined by the formula for calculating $K$ values which can be calculated with the Weischmehter equation [8], with parameters of soil particle size ($M$), organic matter content ($a$), soil structure value ($b$) and soil permeability values ($c$). The $K$ value can then be determined based on the type of soil in the study area as in table 2 below.

Table 2. $K$ value based on the type of soil in the study area.

| Type of Soil          | $K$ Index | Type of Soil          | $K$ Index | Type of Soil          | $K$ Index |
|-----------------------|-----------|-----------------------|-----------|-----------------------|-----------|
| Alluvial              | 0.156     | Red Podsolic          | 0.166     | Red Brown and Yellow Red latosol | 0.046     |
| Andosol               | 0.278     | Yellow Podsolic       | 0.107     | Yellow Podsolic and dark hydromorf | 0.249     |
| Yellow brown Andosol  | 0.298     | Yellow brown Latosol  | 0.091     | Red Brown Latosol and Brown Latosol | 0.067     |
| Andosol and Regosol   | 0.271     | Regosol and Brown latosol | 0.186     | Red Brown Latosol and Red Latosol | 0.061     |
| Latosol               | 0.176     | Brown Latosol         | 0.175     | Red Yellow Podsolic   | 0.166     |
| Regosol               | 0.075     | Red brown Latosol     | 0.062     | Dark blue Regosol and Lytosol | 0.290     |

Source: Bandung Water Resources Research and Development Center, 2015

3.4. Land coverage and management factors ($C$)
Based on the interpretation of a 5 m resolution satellite image, the data is classified based on land use and the value for factor $C$. Because the lowest level of land use in the study area is widely used for mining and open land, the highest value used for land coverage is 0.65. While for non-irrigated agricultural land is different from the use of irrigated agricultural land, $C$ values are used, 0.43 for non-irrigation and 0.02 for irrigated agriculture. Meadows and areas covered by shrub vegetation, depending on the level of coverage, for undisturbed shrubs the value of $C = 0.01$, while partially grassy shrubs used a value of $C = 0.10$. Whereas Plantation areas are given a value of 0.1, while forests, which provide the highest level of protection, use the lowest $C$ value (lower than 0.03).

3.5. Support for land management factors ($P$)
The P factor is used constant prices (equal to 1) in the analysis due to the lack of reliable data sources needed to conduct analyses of various conservation practices that are applied in the watershed areas of the study area. Thus, the resulting analysis does not account for differences in erosion and soil loss due to differences in planting methods and land use practices.

4. Results and Discussion

4.1. Analysis of sediment transport and sedimentation.
Sediment transport analysis uses the USPED (Unit Stream Power Erosion and Deposition) method. The patterns that are modelled on sediment transport and the level of erosion and deposition in the upper
Lematang river sub-basin were analysed for three categories of causative factors, namely topography, topography based on soil erodibility, and topography influenced by soil erodibility and land cover. Includes an analysis of both surface runoff and erosion flow mechanisms calculated using all trigger factors that influence erosion. In the USPED model, the slope factor is influenced by the topographic index, which will affect the K value (soil erodibility), and also influenced by the C value (land use) and P (land management factor) in obtaining sediment transport values. The results of the analysis of sediment transport and deposition, in sub-watersheds are classified for each sub catchment. Exfoliation and sediment rates are classified according to the catchment area of each watershed, to obtain ED values in accordance with sub-watershed boundaries.

Table 3. Sediment transport values for each sub-watershed.

| Sub watershed | Area (Sqr.Km) | Transport Sediment (Kg/m²) | Averagea ED (ton/ha/Year) |
|---------------|---------------|---------------------------|--------------------------|
| Sub-Lematang 1| 38.083        | 9.137                     | -2.303                   |
| Sub-Lematang 2| 22.414        | 23.656                    | 1.265                    |
| Sub-Lematang 3| 42.286        | 13.933                    | -1.651                   |
| Sub-Lematang 4| 39.489        | 21.930                    | -0.456                   |
| Sub-Lematang 5| 47.738        | 6.967                     | 1.417                    |
| Sub-Lematang 6| 44.231        | 22.355                    | -0.528                   |
| Sub-Lematang 7| 29.757        | 18.926                    | -1.193                   |
| Sub-Lematang 8| 59.140        | 35.184                    | 0.001                    |
| Sub-Lematang 9| 20.140        | 11.517                    | -0.037                   |
| Sub-Lematang 10| 41.330       | 12.101                    | -0.380                   |
| Sub-Lematang 11| 52.662       | 16.522                    | -0.179                   |

Based on the above analysis it was found that Sub-Lematang 8 has a fairly high peeling rate of 35,184 kg/m². Whereas sub-Lematang 5 is a maximum sediment deposition area of 1,417 tons/ha/year. If the distribution of sedimentation is analysed based on various factors such as land use and land slope, the results can be seen in the following figure 2.

Figure 1. (a) Average sediment transport of upper Lematang sub-watershed and (b) deposition results from variations of various combinations of factors in the USPED model.
4.2. Average sediment transport and spatial distribution of erosion and sedimentation based on slope and land use functions

Based on the results of overlapping various slope levels with infiltration coefficient (C) of land use, peeling results obtained for each land use, and average values and sediment build up as shown in Table 4. Results of ED classification (peeling from soil above) based on land use, it appears that the largest exploitation is in the irrigated area of 2,139 tons/ha and sediment is in the waters area of 5,226 tons/ha. A low C value indicates that it is naturally more protected from erosion by land flow compared to irrigated gardens and agricultural land that is less resistant to erosion and has the highest C value. The effect of the sediment transport factor is that it will reduce sediment fluctuation in areas that are well protected by vegetation cover and will increase in areas that are less protected by deeper root systems. The inclusion of factor C, significantly changes the distribution of areas with high sediment transport rates, makes the topographic influence less clear and will affect areas that have vegetation cover with low vegetation cover protection, such as in meeting areas with main drainage patterns that are covered by forests and plantations, with reservoir areas and reservoirs.

By adding the land cover factor in the calculation, the erosion and deposition pattern will shift and will see areas with high erosion and the risk of deposition that occurs in contact between agricultural land / grassland and forest land, and seen on slopes with a slope between 15-25% which poorly protected by vegetation cover. This occurs as a result of changes in sediment transport rates associated with the transition from one land cover to another. For example, an increase in the rate of transport towards the valley (as determined by local topography) will cause erosion.

Figure 2. Average Sediment transport and erosion and sediment distribution patterns as a result of land use changes.
Table 4. Average Sediment transport and spatial distribution of erosion and disposition as a result of slope and land use classification.

| Land Use       | Area (Ha)     | Average Value of ED (Ton/Ha) |
|---------------|--------------|-----------------------------|
| Village       | 9,191.875    | 0.8045                      |
| Irrigation    | 1,640.8125   | -2.1390                     |
| Dryland Farming | 5,448.375   | 2.1207                      |
| Garden        | 4,004.8125   | -0.3282                     |
| Plantation    | 2,0581.1250  | 0.1467                      |
| Open Field    | 3,421.8125   | -0.1521                     |
| Forest        | 10,753.7500  | 0.4978                      |
| Water         | 800.4375     | 5.2258                      |
| Open Land Use | 36,5625      | -0.0526                     |

4.3. Average sediment transport and spatial distribution of erosion and deposition as a function of the erodibility factor

Based on the results of the surface slab on the slope of the land, the results of peeling of the soil are obtained for each slope. The average yield and maximum peeling value and sediment build up can be seen in Table 5. If it is analysed based on slope, the sloping area (8-15%) has a high peeling rate of 1.8239 tons/ha and high rainfall in the region is rather steep (16-25%) of 2.1207 tons/ha. Overall, by incorporating the K-factor in the analysis, the spatial pattern of sediment transport capacity reflects the influence of areas with high erosion, and thus sediment flow will have lower values over a wide area across the landscape than having very high values concentrated in a concave areas steep slope. However, because the distribution of soil types is highly correlated with topography, the location is also highly dominated by topography.

Table 5. ED value of each slope classification.

| Slope Class | Range of slope | Area (Ha)     | Average ED (Ton/Ha) |
|-------------|----------------|--------------|---------------------|
| Class 1     | < 8%           | 26,088.3 12  | -0.3297             |
| Class 2     | 8% – 15%       | 7,390.375   | -1.8239             |
| Class 3     | 16% – 25%      | 5,448.375   | 2.1207              |
| Class 4     | 26% – 45%      | 3,167,813   | -0.3282             |
| Class 5     | > 45%          | 1,416,063   | 0.1467              |

The spatial distribution of erosion and sediment is also modified by inclusion of soil accessibility patterns in the sense that it increases the area of the area at high risk of erosion.

Table 6. Value of ED each soil type.

| Soil Type                        | Teksture  | Area (Ha) | Average of ED (ton/Ha) |
|----------------------------------|-----------|-----------|------------------------|
| Assosiation of Brown Alluvial    | Lom Clay  | 4.076     | 1.9201                 |
| Assosiation of Brown Podsolic    | Lom Clay  | 14.390    | -0.3372                |
| Assosiation of Brown Podsolic    | Clay      | 1.474     | 2.0519                 |
| Assosiation Yelow Podsolic & Hydromorf | Clay | 2.802     | -2.2859                |
| Assosiation of                    | Clay      | 6.787     | -1.4316                |
5. Conclusions

Based on the results of the analysis and discussion above, the following conclusions can be concluded:

- The highest slope erosion potential values are on steep slopes (16-25%) and the largest deposits are on sloping slopes (8-15%).
- Analysis of erosion and deposition rates based on land cover, slope and soil type, showed that the area with the highest peeling in the area of irrigated agricultural land was 2.139 tons/ha/year, on a slope of 1.8239 tons/ha/year.
- Analysis of erosion and deposition rates based on land slope, and soil type, areas with alluvial yellow podsolic soil types, amounting to 2.28591 tons/ha/year. While those with high deposits are found in water areas of 5.2258 tons/ha/year. The area above is rather steep with a spatial distribution of deposition of 2.1207 tons/ha/year. While in areas with brown podsolic and podsolic soil types, the spatial distribution of sediment is 2.05188 tons/ha/year.

6. References

[1] D. D. A. Putranto, Sarino, and A. L. Yuono, “Spatial distribution level of land erosion disposition based on the analysis of slope on Central Lematang sub basin,” in AIP Conference Proceedings, 2017.
[2] E. B. Dinar DA Putranto, “Effect of sedimentation volume on productivity and dwelling time of ships at bom baru port,” in MATEC Web of Conferences, 2017, vol. 138.
[3] S. Pelacani, M. Märker, and G. Rodolfi, “Simulation of soil erosion and deposition in a changing land use: A modelling approach to implement the support practice factor,” Geomorphology, 2008.
[4] A. Pistocchi, G. Cassani, and O. Zani, “Use of the USPED model for mapping soil erosion and managing best land conservation practices,” Proc. First Bienn. Meet. Int. Environ. Model. Softw. Soc. Integr. Assess. Decis. Support, vol. 3, pp. 163–168, 2002.
[5] A. J. Parsons, A. D. Abrahams, and J. Wainwright, “Rainsplash and erosion rates in an interrill area on semi-arid grassland, Southern Arizona,” Catena, 1994.
[6] Dinar DA Putranto, MODEL MEDAN DIGITAL UNTUK PEMODELAN RAINFALL-RUNOFF ANALISIS SEDIMENTASI SECARA REGIONAL PADA DAS MUSI, 3rd ed. Palembang: Lembaga Penelitian dan Pengabdian Kepada Masyarakat UNSRI, 2015.
[7] G. Munda, P. Nijkamp, and P. Rietveld, “Qualitative multicriteria methods for fuzzy evaluation problems: An illustration of economic-ecological evaluation,” Eur. J. Oper. Res., vol. 82,
1, pp. 79–97, Apr. 1995.

[8] M. A. Nearing, “Soil Erosion and Conservation,” in *Environmental Modelling: Finding Simplicity in Complexity: Second Edition*, 2013.

[9] M. Lazzari, D. Gioia, M. Piccarreta, M. Danese, and A. Lanorte, “s,” *Catena*, vol. 127, pp. 323–339, 2015.

**Acknowledgment**

High appreciation to the Institute of Research and Community Services of the University of Sriwijaya, which has provided superior research funding for universities, so that the results of this study could be completed.