Vol. 12, No. 1 (2023) : 14 - 27 DOI : http://dx.doi.org/10.23960/jtep-l.v12i1.14-27

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Spatial Modeling of Vegetation Cover for Soil Erosion Control Based on Arc GIS and the RUSLE Models

Dimas Prabowo Harliando[1], Chandra Setyawan[1]✉, Hanggar Ganara Mawandha[1]

[1]Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Yogyakarta, INDONESIA.

Article History :

Received : 7 June 2022
Received in revised form : 15 September 2022
Accepted : 14 Oktober 2022

Keywords :

Soil erosion,
RUSLE model,
GIS,
Serayu watershed,
Vegetation cover

✉Corresponding Author:
chandra.tep@ugm.ac.id

ABSTRACT

Environmental damage control needs to be applied through appropriate conservation programs. This study aims to understand the distribution of soil erosion and the effectiveness of soil erosion control by using vegetation cover. Soil erosion modeling and its correlation to vegetation cover was performed by using an Arc GIS based model of the Revised Universal Soil Loss Equation (RUSLE) through five scenarios of vegetation landscape cover such as 10%, 15%, 20%, 25%, and 30% of the total area of the study site. Five parameters namely rain erosivity (R), soil erodibility (K), slope-length (LS) and crop management (C) and conservation practices (P) factor were used to calculate soil erosion. The results indicated 82.25 tons/ha/year soil erosion reduction due to enhancement of vegetation cover from the actual condition 0.73% to the 30% vegetation cover condition. The increase of 5% vegetation landscape cover (forest) detracted the soil erosion rate by 10,20 tons/ha/year. Very high and high soil erosion hazard levels were found in the northern, east, and west watershed areas.

1. INTRODUCTION

Indonesia is a tropical country with a very large number of watersheds. The island of Java, the most densely populated island in Indonesia has 1200 watersheds spread from the western end of Banten Province to the eastern end of East Java Province. However, watershed damage has been increased, expedited by the using of natural resources as a result of population growth and economic development, policies that have not favored the preservation of natural resources, and the lack of public awareness and participation in the context of the use and preservation of natural resources (Sonapasma, 2010), this causes the watershed to gradually reach critical to very critical levels condition.

According to the 2018 Central Statistics Agency, the total area of critical land in Indonesia was 9,453,729 ha. Meanwhile, the area of very critical land was 4,552,721 ha. This is one indicator that can be considered in efforts to improve land management in order to preserve existing natural resources, especially in the watersheds. The fruitfulness of watershed management is indicated from the balance of discharge fluctuations, river sediment load, and the sustainability of water sources. Another important indicator is soil erosion. Watershed defense against erosion is closely related to land management activities in the watershed area (Herawati, 2010).

The soil system is the component of an ecosystem that has important role for population, especially related to food security, climate mitigation, and nutrient and water cycles (de Vries *et al*., 2012). However, soil systems face the threat of erosion caused by climate change and intensive land cultivation. Soil erosion is the process of soil particle loss or parts of soil from upstream area transported by water or wind to another place downstream. Eroded soil moved by overland flow is deposited as a sediment in places where water flow is retarded such as rivers, irrigation canals, reservoirs, lakes, or river mouths. This has an impact on sediment deposition in the river, triggering more frequent floods in the wet season and drought in the dry season (Arsyad, 2010).

A watershed (DAS) is a land area that accommodates, stores, and drains rainwater to a lake or sea naturally. Soil system is one of the most important component that affect the watershed health condition as reported by Mahdi (2017) and Retyanto (2016). The damage of soil system reflected from the high river sedimentation indicates a problem as found in Serayu Watershed. The watershed has important roles for water conservation, electric generation, agricultural irrigation, and other purposes. An investigation is required to understand the present rate and spatial distribution of soil loss (erosion) in Serayu Watershed as the basis for conservation planning. Measurement of the rate of soil erosion jeopardy has been carried out with various models. The revised Universal Soil Loss Equation (RUSLE) was the most frequently used model developed by Renard *et al*. (2007). The USLE model is widely used to quantitatively estimate soil erosion in a plot while the RUSLE model is used to estimate soil erosion over a wider area and conditions. The use of the model (RUSLE) was chosen based on the conditions of the study area and the results of previous research. RUSLE model has been used and showed a good performance in soil erosion studies under various climate conditions (Demirci & Karaburun, 2012; El-Aroussi *et al*., 2013; Kumar & Kushwaha, 2013).

RUSLE has also been used for soil erosion studies in Indonesia, however most of those studies were not completed with a model validation. Lack of field measurement data has become a challenge in the using of soil erosion model. In this study, RUSLE model was validated by using field measurement data of sedimentation in the study site. It is one of a way for RUSLE model validation, besides using an erosion plot (Setyawan *et al*., 2019). RUSLE was then used for soil erosion modeling under five vegetation cover scenarios condition. The study aims for provides a reference to determine a minimal standard of vegetation cover for conservation purpose in a watershed scale.

2. MATERIALS AND METHODS

This study was performed from 2021 to 2022, where the data were collected from various sources from the period of 2016 to 2021 from six rainfall stations located in catchment area of the PB Sudirman Reservoir, namely Sigaluh, Batur, Pagentan, Karangkobar, Garung, and Kertek Rain Stations. Some materials were used this study, such as: (1) rainfall data and maps obtained from the Central Java Regional Office of Serayu Opak Progo and the Meteorology, Climatology and Geophysics Agency. This data was used to determine the value of the rain erosivity factor or *R*, (2) soil type data, and the *K* factor value (soil erodibility index), (3) land use maps, obtained from Geospatial Information Agency (Badan Informasi Geospasial) (https://tanahair.indonesia.go.id/) to determine the land use and conservation practices factor or CP, (4) Contour Maps and DEM (Digital Elevation Model) obtained from BIG , to determine the value of the length and slope factor or *LS*, (5) Serayu watershed maps, and (6) ArcGIS software used for spatial analysis and modeling. In addition, a double mass curve analysis was carried out at three stations, namely Sigaluh, Batur, and Pagentan to see the consistency of the rainfall data.

2.1. Study Area

Implementation of the present study was performed in the upstream area of the Serayu watershed, Central Java Province, Indonesia (Figure 1). The Serayu watershed covers several districts in Central Java, namely Wonosobo, Banjarnegara, Banyumas and Cilacap regencies. The upstream Serayu watershed has an area of 98,280.96 Ha, located in Banjarnegara and Wonosobo Regencies and geographically is located at 07^{o} 05' - 07^{o} 4' South Latitude and 108^{o} 56'- 110^{o} 05' East Longitude with an altitude of 213-3238 above mean sea level. The watershed was dominated by areas with 8-15% land slope.

K

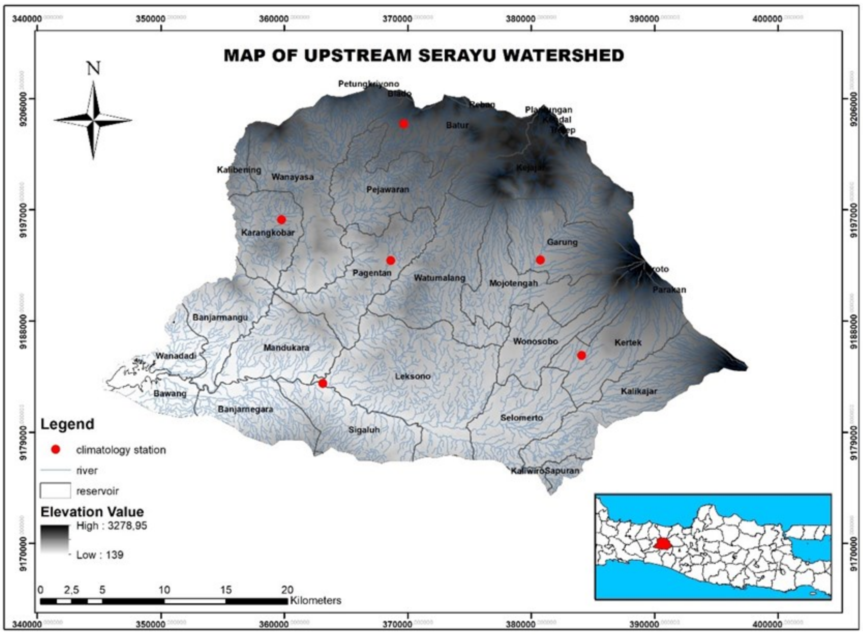

Figure 1. Map of upstream Serayu watershed

2.2. Data Analysis

RUSLE model (Renard *et al*., 1997) was used for soil loss (erosion) modeling in the present study. This model (RUSLE) considers five factors affecting the value of soil erosion such as rain erosivity (*R*), soil erodibility factor (*K*), length and slope factor (*LS*), vegetation cover factor (*C*), and soil conservation practices (*P*) as written in Equation 1.

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where *A* is the average annual erosion (ton.ha^{-1}.year^{-1}), *R* is the rainfall erosivity factor (MJ.mm.ha.hour^{-1}.year^{-1}), *K* is the soil erodibility factor (ton.hour.MJ^{-1}.mm^{-1}), *LS* is the factor of the length and slope of the land (without unit), *C* is the factor of vegetation management (without unit), and *P* is the factor of soil conservation (without unit).

In the present study, soil erosion value in the existing condition was classified into five classes category (Table 1), to indicate the level of erosion hazard. It determined based on the comparison between the magnitude of the rate of soil erosion and the tolerable soil erosion (Roeska *et al*., 2017). All data were presented in raster format with 30 map resolution in Arc GIS 10.8.

Table 1. Classification of Soil Erosion Risk Rate

Class	Erosion Rate (ton/ha/yr)	Classification
I	0 to 15	Very Low
II	15 to 60	Low
III	60 to 180	Moderate
IV	180 to 480	Heavy
V	> 480	Very heavy

Source: (Arsyad, 2010)

2.2.1. Rainfall Erosivity Factor

The value of *Rm* (rainfall erosivity factor) was assessed from monthly rainfall (*Rb*, cm) by using the equation proposed by Lenvain (Asdak, 2007):

$$Rm = 2{,}21\,(Rb)^{1{,}36} \tag{1}$$

2.2.2. Soil Erodibility (K) Factor

Soil erodibility factor (*K*) value was estimated based on references to several soil types in Indonesia as shown in Table 2.

Table 2. Reference K Value for Various Lands in Indonesia

No	Soil Type	*K* Value
1	Latosol red	0.12
2	Latosol red yellow	0.26
3	Latosol	0.31
4	Latosol brown	0.23
5	Grumusol	0.20
6	Alluvial	0.47
7	Regosol	0.11
8	Lithosol	0.29

Source: Asdak (2014)

2.2.3. Slope Length (*LS*) Factor

Slope Length (LS) factor value was estimated based on the land slope class as shown in Table 3. using a Land slope map was obtained from contour data in the study site.

2.2.4. Land Use Factors and Conservation Practices (*CP*)

Land use factors and conservation practices (CP) value was estimated based on land use types in the study area as figured in Table 4.

Table 3. Relationship between steepness of slope and LS value

Slope Class	Land Slope (%)	LS Value
1	0 to 8	0.4
2	8 to 15	1.4
3	15 to 25	3.1
4	25 to 40	6.8
5	> 40	9.5

Source: Department of Forestry, 1998 (Yudhistira *et al*., 2021).

Table 4. CP factor values for different land use types in Indonesia

Type of Land Use	CP
Lake	0
Building	0
Forest	0.01
Grassland	0.02
Plantation	0.01
Settlement	0
Swamp	0.01
Rice field	0.02
Bush	0.01
River	0
Moor/Field	0.19
Reservoir	0

Source : Asdak (2014)

2.2.5. Vegetation Cover Spatial Modeling

Vegetation cover modeling was carried out in a GIS by increasing the value of the vegetation cover from existing value condition into five scenarios value such as 10%, 15%, 20%, 25%, and 30%, respectively. Soil erosion rates were then calculated under existing and five scenarios condition. Five scenarios of vegetation cover were carried out on all watersheds by replacing the CP values located at high LS values with forest CP values. Model validation is performed by comparing the value of the calculated soil erosion rate using the model with the results of direct measurements in the study site.

3. RESULTS AND DISCUSSION

3.1. Rainfall Erosivity (*R*) Factor

Rainfall erosivity is the ability of rain to erode the surface layer of the soil, causing erosion. Factors affecting the erosivity of rain include the amount, intensity of velocity, raindrop size, and the distribution of the size of the falling raindrops (Blanco & Lal, 2010; Morgan, 2005). In the present study, annual rainfall erosivity values in the upstream Serayu watershed were various from 3204.86 – 3620.15 MJ/ha (Figure 2). The value of R (rainfall erosivity) factor is directly proportional to the value of precipitation (rainfall) in the study site. In addition, a double mass curve analysis was carried out at three stations, namely Sigaluh, Batur, and Pagentan to see the consistency of the rainfall data used. According to the results of the double mass curve analysis, it can be seen that the R^2 value for the three tested stations is > 0.70 (Figure 3, 4, 5). This shows that the rainfall data used is quite consistent and does not need to be corrected. The rise of rainfall will increase rainfall erosivity and soil erosion as well (Mohamadi & Kavian, 2015; Ran *et al*., 2012). A higher rainfall intensity causes the soil to be more easily eroded by surface runoff due to high soil moisture in the topsoil layer (Wu *et al*., 2018).

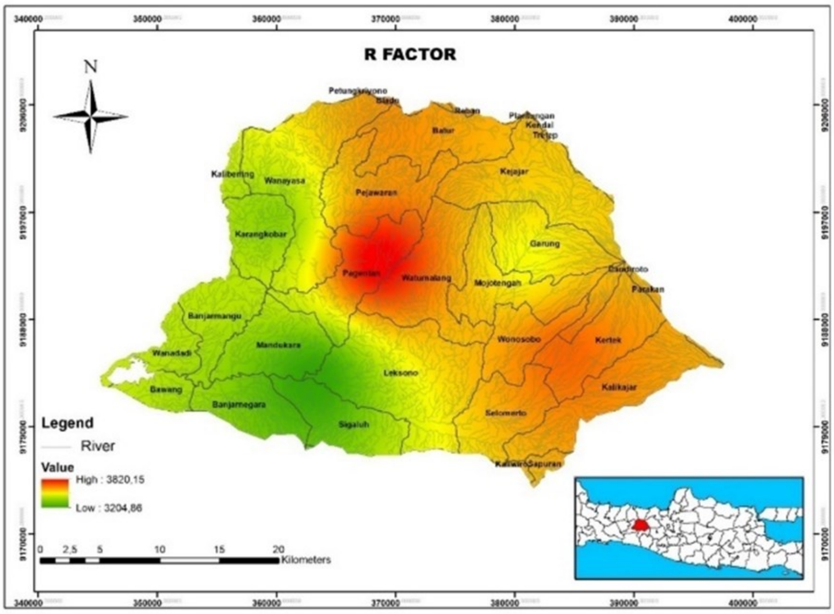

Figure 2. Rain erosivity map of the upstream Serayu watershed

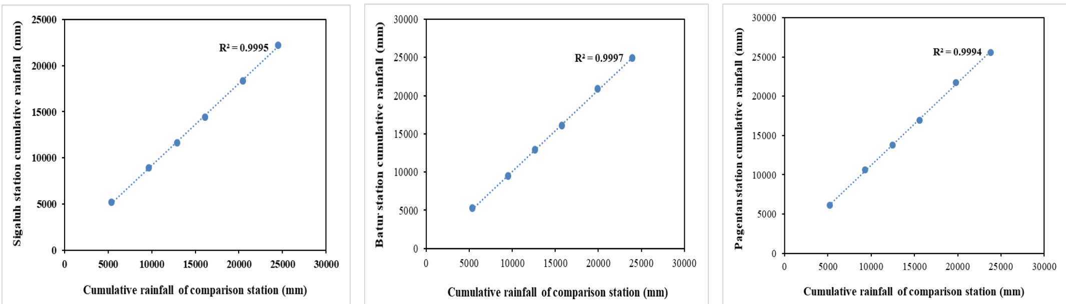

Figure 3. Rainfall consistency graph (From left: Sigaluh, Batur, and Pagentan station)

3.2. Soil Erodibility (*K*) Factor

Soil erodibility factor (*K*) indicates the level of resistance of soil particles to peeling by the kinetic energy of rainwater. Erodibility is affected by the texture, the structure, the permeability, and the organic material content of soil (Cakratiwi & Murti, 2020). In the present study, the value of K factor was obtained based on soil types in the study site. There were four types of soil found in the area of study namely alluvial, grumusol, latosol and regosol. The erodibility factor (*K*) values for those soil types were 0.11, 0.20, 0.31, and 0.47. respectively. The spatial distribution of soil erodibility values in the upstream Serayu watershed is shown in Figure 4.

3.3. Slope Length (LS) Factor

The *LS* factor in this study was determined based on land slope of study site as shown in Figure 5. The figure indicated that the value of LS factor in the study site (upstream Serayu watershed) were various from 0.4 to 9.5. The highest LS values were found in the sub-districts of Kejajar, Candiroto, Batur, Banjarmangu, and Karangkobar. In Kejajar and Batur sub-districts, there was a Bismo Mountain that has a land with a high slope of about 25-40%. Candiroto sub-district is also located under the foot of Sindoro mountain so it has about 25-40% of land slope. Meanwhile, the sub-districts of Banjarmangu and Karangkobar were located around the slopes of Damar mountain with land slope value between 25-40%. The slope of slope affects erosion through runoff. The slope the steeper and longer will increase the amount of erosion, if the slope is steeper, then the velocity of runoff increases (Ansar *et al*., 2020). Soil erosion increases with the rise of LS factor values (Thomas *et al*., 2018).

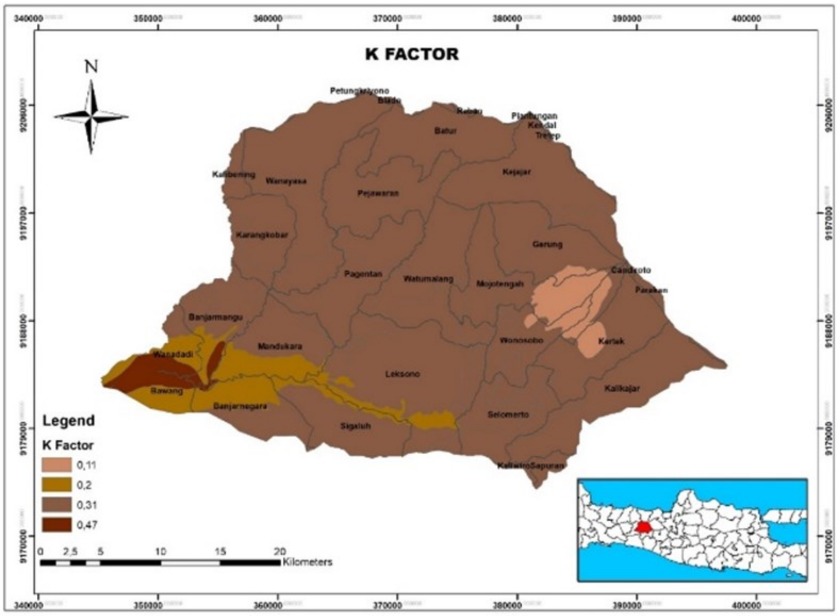

Figure 4. Map of soil erodibility in the upstream Serayu watershed

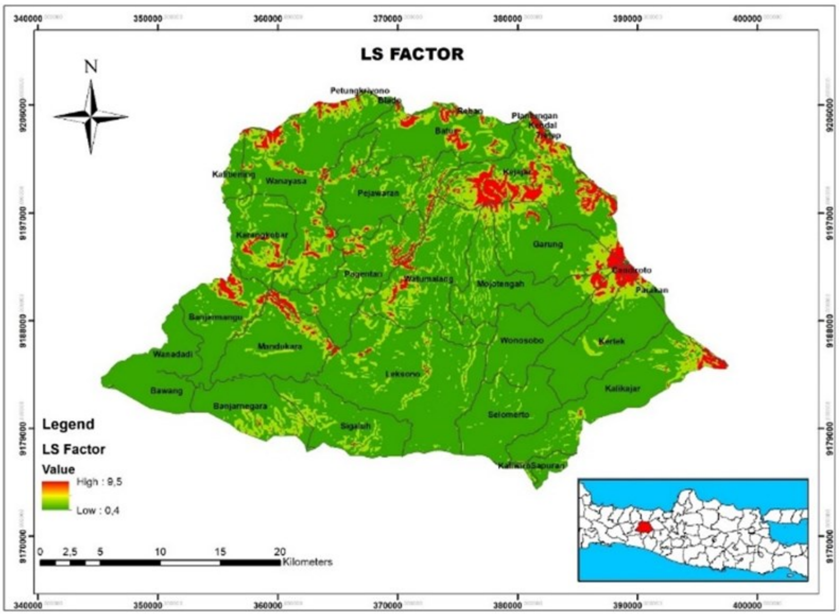

Figure 5. Map of the LS upstream Serayu watershed

3.4. Land Use Factors and Conservation Practices (*CP*)

The CP factor is one of the critical elements in controlling the risk of soil loss (erosion) in land. CP factor effect on soil loss has a relation with land use/land cover types particularly related to planting and land use arrangement (Kuok *et al*., 2013; Patil & Sharma, 2013). CP factor in this study was gained based on land use/land cover types in the study site. Most of land use/land cover in the upstream Serayu watershed was used for agricultural activities such as plantations and irrigated rice fields and rainfed rice fields. The area of land used for agricultural activities reaches 56% of the total area of the upstream Serayu watershed. The CP value in the upstream Serayu watershed is shown in Figure 6.

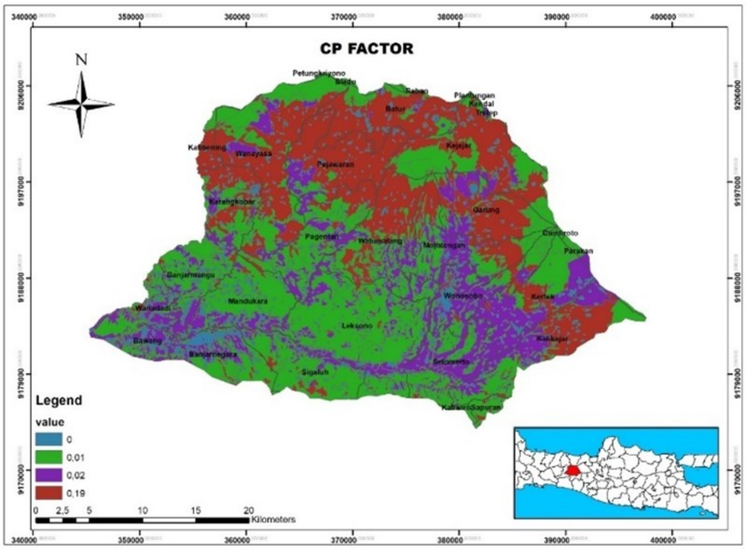

Figure 6. Map of CP factors for the upstream Serayu watershed

3.5. Vegetation Cover Modeling

GIS splits all map data in grids cell (land unit) with 30-meter sizes. Vegetation modeling in this study was carried out by changing land units with high *CP* and *LS* value into lowest value in the form of forest vegetation through five scenarios, namely 10%, 15%, 20%, 25%, and 30%. The *CP* value used in this modeling is the forest *CP* value of 0.01. This *CP* value was used to replace the *CP* value of land units with high *CP* and *LS* values. Changes in vegetation cover are carried out at intervals of *LS* 1.4 - 9.5. Ochoa *et al*. (2016) noted that land covered with vegetation can significantly reduce the risk of soil erosion even though it has a sloping topography. This change of *CP* value in this study can be recognized from the increasing green area as shown in Figure 7.

3.5. Soil Erosion in Existing Condition

Soil loss (erosion) assessment by using the RUSLE model showed an average value of 104.63 tons/ha/year. This value was categorized as moderate category based on the soil loss critical level classification by the Department of Forestry, Indonesia in 1998 (Harjianto *et al*., 2015). This result was then validated by using field sedimentation measurement data which was obtained from PT. Indonesia Power for Mrica Generation Unit as shown in Table 5. The sedimentation measurement is carried out by echo sounding It can be recognized that the average value of sediment from 1989 to

2021 was 3.9 million m^3. This value was then converted based on bulk density of the soil in the study site (2,54 ton/m^3), so that the value equal to 102.04 tons/ha/year. Based on these two values, it can be seen that there was no significant difference value, mean that the RUSLE model has a good performance.

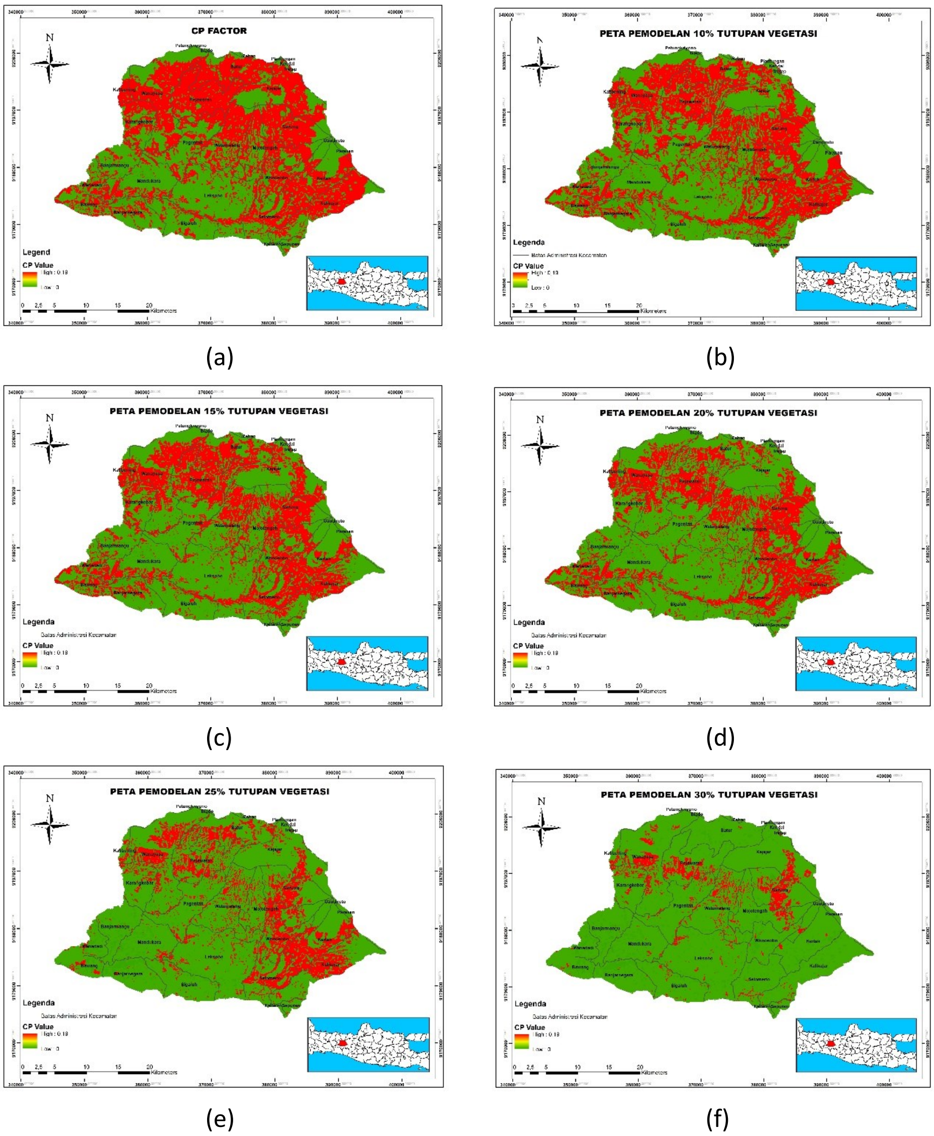

Figure 7. Map of CP factor: (a) existing condition, (b) modeling map of 10% vegetation cover, (c) 15%, (d) 20%, (e) 25%, (f) 30%

3.5. Soil Erosion in Existing Condition

Soil loss (erosion) assessment by using the RUSLE model showed an average value of 104.63 tons/ha/year. This value was categorized as moderate category based on the soil loss critical level classification by the Department of Forestry, Indonesia in 1998 (Harjianto *et al*., 2015). This result was then validated by using field sedimentation measurement data which was obtained from PT. Indonesia Power for Mrica Generation Unit as shown in Table 5. The sedimentation measurement is carried out by echo sounding It can be recognized that the average value of sediment from 1989 to 2021 was 3.9 million m^3. This value was then converted based on bulk density of the soil in the study site (2,54 ton/m^3), so that the value equal to 102.04 tons/ha/year. Based on these two values, it can be seen that there was no significant difference value, mean that the RUSLE model has a good performance.

Table 5. PB Sudirman reservoir sediment volume measurement data

Measurement Year	Sediment Vol. (m^3)	Measurement Year	Sediment Vol. (m^3)	Measurement Year	Sediment Vol. (m^3)
1989	3.382.678	2000	7.027.165	2011	5.318.774
1990	3.441.288	2001	3.381.701	2012	4.141.774
1991	6.018.471	2002	3.523.077	2013	2.480.956
1992	3.782.662	2003	4.435.166	2014	1.707.932
1993	3.487.578	2004	2.895.168	2015	4.355.431
1994	3.386.697	2005	4.627.772	2016	3.638.728
1995	5.022.637	2006	3.992.261	2017	5.569.249
1996	4.604.384	2007	3.772.284	2018	2.250.007
1997	2.174.447	2008	4.299.048	2019	2.674.492
1998	5.999.578	2009	4.763.895	2020	2.660.405
1999	4.537.659	2010	4.054.992	2021	2.894.875
Average all			3.948.583		

Source: PT. Indonesia Power for Mrica Generation Unit (2022)

Table 6. Soil loss (erosion) distribution in upstream Serayu watershed

Soil Loss (Erosion) rate (ton.ha^{-1}.year^{-1})	Category	Coverage area km^2	%
0-15	Very low	41278	42%
15-60	Low	23587.43	24%
60-180	Moderate	15724.95	16%
180-480	Heavy	10810.91	11%
>40	Very heavy	5896.86	6%

Soil erosion value in the existing condition was classified in five classes to show the spatial distribution of soil erosion under various classes (Table 6). The classification indicates the study site was dominated by low class erosion (42% of the area). Area with heavy and very heavy class of soil erosion was about 17% of the total area.

The model (RUSLE) was then applied for estimating soil erosion under five scenarios condition. The increase of vegetation landscape cover, reduce soil loss in each scenario condition as shown in Table 7 and Figure 8.

Table 7. Average soil erosion value

Condition	Average rate of soil erosion ton/ha/year
Existing	104,63
10% Vegetation cover model	63,21
15% Vegetation cover model	56,77
20% Vegetation cover model	47,04
25% Vegetation cover model	29,67
30% Vegetation cover model	22,38

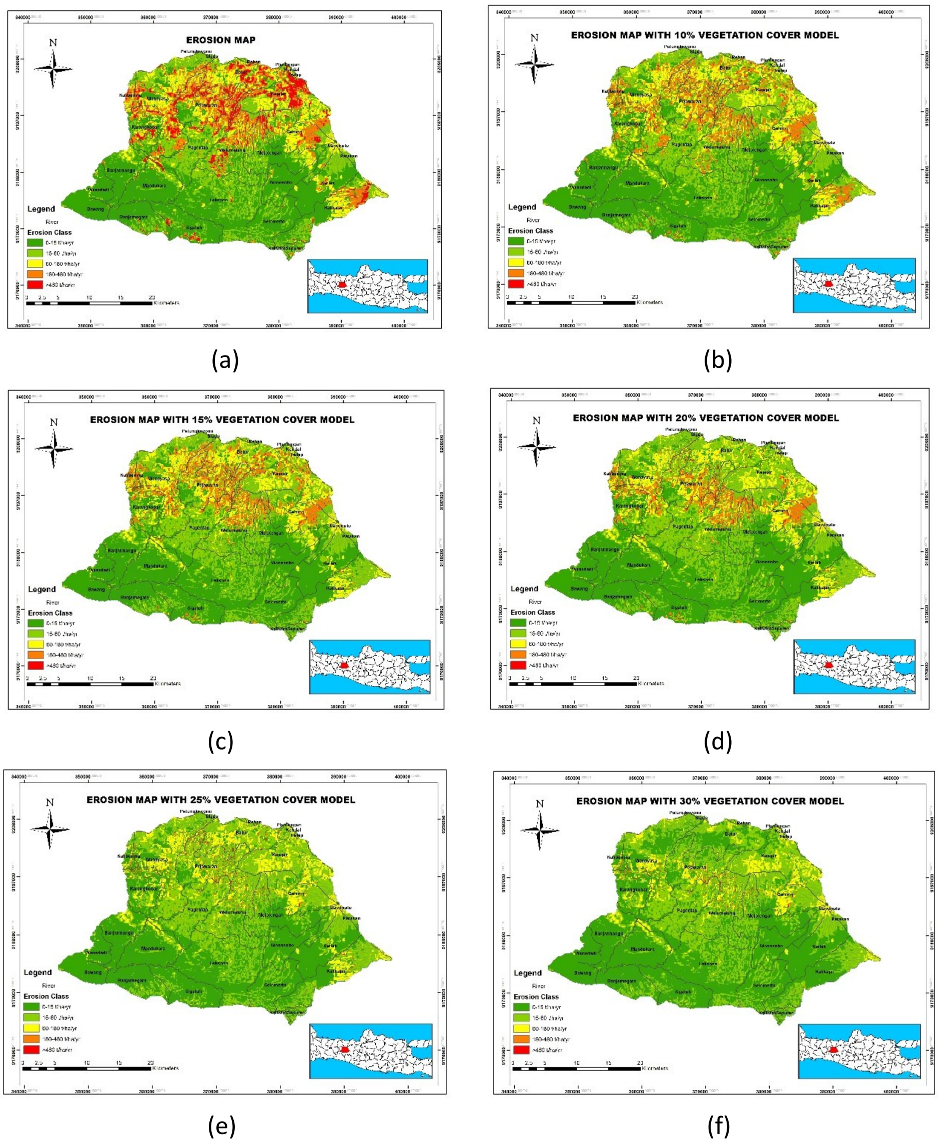

Figure 8. Distribution map of erosion rates: (a) existing condition, (b) modeling vegetation cover 10%, (c) 15%, (d) 20%, (e) 25%, (f) 30%

In 10% vegetation cover condition, the average value of soil erosion decreases from the existing condition value of 104.63 tons/ha/year to 63.21 tons/ha/year. However, in the 10% vegetation condition, the average erosion rate was still in the moderate category (60-180 tons/ha/year). The average value of the erosion rate used as tolerable limit is 60 tons/ha/year (low erosion category). In 15% vegetation cover condition, soil erosion decreased into tolerable limit. Vegetation cover can be done up to 50% but the use of 30% vegetation cover is based on the Law of the Republic of Indonesia No. 41 of 1999 (Siscawati *et al*., 2017). Total reduction of soil erosion value from the existing conditions to 30% vegetation landscape coverage was 82.25 tons/ha/year. This indicated that the increase of vegetation coverage has an important impact on decreasing of soil loss.

This findings are appropriate with previous researches that discussed about the impact of vegetation cover on soil erosion reduction (Prasetyo, 2021; Tadesse *et al*., 2017), which noted that the value of the erosion rate on land that has vegetation cover will be lower when compared to the land that does not have vegetation cover or which has been converted into agricultural and settlement practices. Besides that, the existence of a root system in plants can increase resistance to soil erosion, especially in the topsoil (Li *et al*., 2017). Vegetation cover factor and conservation practices were factors that have a major effect on changes in soil loss rate. The wider vegetation landscape can reduce the kinetic energy of rain drop before it reaches the ground surface (Chen *et al*., 2018). This study also revealed that though the soil loss rate in the study area was in moderate category (in general), but some specified area contributed a significant number of soil erosion value.

4. CONCLUSION

Model validation by using field measurement data of sedimentation indicates that the RUSLE model has a good performance for soil loss assessment in the study site. The value of the soil loss rate in the study site (upstream area of the Serayu watershed) was 104.63 tons/ha/year (moderate category). Total reduction of soil loss from the actual condition of vegetation cover to 30% of vegetation landscape coverage was 82.25 tons/ha/year. The 5% increase of vegetation landscape coverage reduces the soil loss rate by 10.20 tons/ha/year. High category soil erosions were found in several points in the northern, western, and eastern watersheds with high slopes and agricultural land use types. Soil erosion control needs to be focused on these areas. The most dominant parameters affecting soil erosion were land use factors and conservation practices (CP). Thus, it is necessary to have a strategy for land conservation efforts, especially in areas that have high and very high soil loss rates. Vegetatively, this can be done through agroforestry, the use of cover crops, and the use of grass strips. Meanwhile, mechanically it can be done by making bund terraces and bench terraces.

Acknowledgement

Acknowledgments were conveyed to all parties who have helped in completing this research, namely PT. Indonesia Power for Mrica Generation Unit, Meteorology, Climatology and Geophysics Agency of Central Java, Department of Agricultural and Biosystems Engineering Faculty of Agricultural Technology Universitas Gadjah Mada which provided research facilities and Directorate of Research Universitas Gadjah Mada which provided research fund (RTA Research Grant).

REFERENCES

Ansar, A., Murad, M., Putra, G.M.D., Hartuti, H. (2020). Pemetaan lahan pertanian di Kabupaten Lombok Timur menggunakan sistem informasi geografis (SIG). *Jurnal Teknik Pertanian Lampung*, ***9***(2), 140-148. https://doi.org/10.23960/jtep-l.v9i2.140-148.

Arsyad, S. (2010). *Konservasi Tanah & Air*. IPB Press, Bogor.

Asdak, C. (2014). *Hidrologi dan Pengelolaan Daerah Aliran Sungai*. 6th ed. Gadjah Mada University Press, Yogyakarta.

Blanco, H., & Lal, R. (2010). *Principles of Soil Conservation and Management*. Springer, Dordrecht.

Cakratiwi, E., & Murti, S.H. (2020). Pemanfaatan citra PJ dan SIG untuk penentuan tingkat bahaya erosi di Sub Das Merawu, DAS Serayu. *Jurnal Bumi Indonesia*, 9.

Chen, H., Zhang, X., Abla, M., Lü, D., Yan, R., Ren, Q., Ren, Z., Yang, Y., Zhao, W., Lin, P., Liu, B., &

Yang, X. (2018). Effects of vegetation and rainfall types on surface runoff and soil erosion on steep slopes on The Loess Plateau, China. *Catena*, ***170***, 141–149. https://doi.org/10.1016/j.catena.2018.06.006

de Vries, F.T., Liiri, M.E., Bjørnlund, L., Bowker, M.A., Christensen, S., Setälä, H.M., & Bardgett, R.D. (2012). Land use alters the resistance and resilience of soil food webs to drought. *Nat. Clim. Change*, ***2***, 276–280. https://doi.org/10.1038/nclimate1368

Demirci, A., & Karaburun, A. (2012). Estimation of soil erosion using RUSLE in a GIS framework: A case study in The Buyukcekmece Lake Watershed, Northwest Turkey. *Environ. Earth Sci*., ***66***, 903–913. https://doi.org/10.1007/s12665-011-1300-9

El-Aroussi, O., El Garouani, A., & Jabrane, R. (2013). Modelling and mapping of soil erosion on The Oued El Malleh catchment using remote sensing and GIS. *J. Urban Environ. Eng*., ***7***, 302–307.

Harjianto, M., Sinukaban N., Tarigan S.D., & Haridjaja, O. (2015). Erosion prediction and soil conservation planning in Lawo watershed Indonesia. *J. of Environ. and Earth Sci.* 5 (6), 40 -50.

Herawati, T. (2010). Analisis spasial tingkat bahaya erosi di Wilayah DAS Cisadane Kabupaten Bogor. *J. Penelit. Hutan dan Konserv. Alam*, ***7***, 413–424. https://doi.org/10.20886/jphka.2010.7.4.413-424

Kumar, S., & Kushwaha, S.P.S. (2013). Modelling soil erosion risk based on RUSLE-3D using GIS in a Shivalik Sub-Watershed. *J. Earth Syst. Sci*., ***122***, 389–398. https://doi.org/10.1007/s12040-013-0276-0

Kuok, K., Mah, D., & Po Chan, C. (2013). Evaluation of C and P factors in universal soil loss equation on trapping sediment: Case study of Santubong River. *J. Water Resour. Prot*., ***05***, 1149–1154. https://doi.org/10.4236/jwarp.2013.512121

Li, Q., Liu, G.-B., Zhang, Z., Tuo, D.-F., Bai, R., & Qiao, F. (2017). Relative contribution of root physical enlacing and biochemistrical exudates to soil erosion resistance in The Loess Soil. *Catena*, ***153***, 61–65. https://doi.org/10.1016/j.catena.2017.01.037

Mahdi, L.M.A. (2017). Pemanfaatan citra Landsat 8 Multitemporal untuk pemetaan muatan padatan tersuspensi pada muara Sungai Serayu Jawa Tengah. [*Undergraduate Thesis*]. Universitas Gadjah Mada, Yogyakarta.

Mohamadi, M.A., & Kavian, A. (2015). Effects of rainfall patterns on runoff and soil erosion in field plots. *Int. Soil Water Conserv. Res*., ***3***, 273–281. https://doi.org/10.1016/j.iswcr.2015.10.001

Morgan, R.P.C. (2005). *Soil Erosion and Conservation*, 3rd ed. Blackwell Pub, Malden, MA.

Ochoa, P.A., Fries, A., Mejía, D., Burneo, J.I., Ruíz-Sinoga, J.D., & Cerdà, A. (2016). Effects of climate, land cover and topography on soil erosion risk in a semiarid basin of The Andes. *Catena*, ***140***, 31–42. https://doi.org/10.1016/j.catena.2016.01.011

Patil, R.J., & Sharma, S.K. (2013). Remote sensing and GIS based modeling of crop/cover management factor (C) of USLE in Shakker River Watershed. *Proceedings of International Conference on Chemical, Agricultural and Medical Sciences* (CAMS-2013) Dec. 29-30, 2013 Kuala Lumpur (Malaysia). http://dx.doi.org/10.15242/IICBE.C1213023

Prasetyo, A. (2021). Pemodelan Pengendalian Erosi Tanah Menggunakan Tutupan Vegetasi Berbasis Geographic Information System (GIS) Pada Daerah Aliran Sungai Progo Hulu. [*Undergraduate Thesis*]. Universitas Gadjah Mada, Yogyakarta.

PT. Indonesia Power Mrica Generation Unit, 2022. *Data Pengukuran Sedimentasi Waduk PB. Soedirman*. PT. Indonesia Power Unit Mrica.

Ran, Q., Su, D., Li, P., & He, Z. (2012). Experimental study of the impact of rainfall characteristics on runoff generation and soil erosion. *J. Hydrol*. ***424–425***, 99–111. https://doi.org/10.1016/j.jhydrol.2011.12.035

Renard, K.G., Foster, G.R., Weesies, G.A., Mccool, D.K., & Yoder, D.C. (1997). *Predicting Soil Erosion by Water : A Guide to Conservation Planning with The Revised Universal Soil Loss Equation* (*RUSLE*). Agricultural Handbook Number 709. USDA-ARS.

Retyanto, B.D. (2016). Analisis faktor penyebab longsor tebing daerah aliran sungai serayu untuk pertimbangan sebagai daerah pemukiman di Kabupaten Wonosobo. *Jurnal PPKM II*, ***7***, 82-88.

Roeska, E., Yunus, Y., & Saleh, S.M. (2017). Tingkat bahaya erosi dan faktor keamanan lereng pada Jalan Banda Aceh - Calang. *Jurnal Teknik Sipil*, ***6***(2), 205-214.

Setyawan, C., Lee, C.-Y., & Prawitasari, M. (2019). Investigating spatial contribution of land use types and land slope classes on soil erosion distribution under tropical environment. *Natural Hazards*, ***98***, 697–718. https://doi.org/10.1007/s11069-019-03725-x.

Siscawati, M., Banjade, M.R., Liswanti ,N., Herawati, T., Mwangi, E., Wulandari, C., Tjoa, M., & Silaya, T. (2017). Overview of forest tenure reforms in Indonesia. Working Paper 223. Bogor, Indonesia: CIFOR .

Sonapasma, D.M. (2010). Prediksi Erosi dan Perencanaan Konservasi Tanah dan Air pada Sub DAS Unda Hulu. [*Undergraduate Thesis*]. Jurusan Ilmu Tanah, Fakultas Pertanian, Universitas Udayana. Denpasar.

Tadesse, L., Suryabhagavan, K.V., Sridhar, G., & Legesse, G. (2017). Land use and land cover changes and soil erosion in Yezat Watershed, North Western Ethiopia. *International Soil and Water Conservation Research*, ***5***(2), 85–94. https://doi.org/10.1016/j.iswcr.2017.05.004

Thomas, J., Joseph, S., & Thrivikramji, K.P. (2018). Estimation of soil erosion in a rain shadow river basin in the southern Western Ghats, India using RUSLE and transport limited sediment delivery function. *International Soil and Water Conservation Research*, ***6***(2), 111–122. https://doi.org/10.1016/j.iswcr.2017.12.001

Wu, B., Wang, Z., Zhang, Q., & Shen, N. (2018). Distinguishing transport-limited and detachment-limited processes of interrill erosion on steep slopes in the Chinese loessial region. *Soil and Tillage Research*. ***177***, 88–96. https://doi.org/10.1016/j.still.2017.12.005

Yudhistira, A., Setyawan, C., Ngadisih, & Tirtalistyani, R. 2021. DEM and land slope based method of RUSLE LS factor calculation for soil erosion assessment. *IOP Conf. Series: Earth and Environmental Science*, 686. https://doi:10.1088/1755-1315/686/1/012033