SCIREA Journal of Environment

http://www.scirea.org/journal/Environmental

January 1, 2023

Volume 7, Issue 1, February 2023

https://doi.org/10.54647/environmental61328

PREDICTION OF LAND EROSION IN THE CATCHMENT AREA OF THE DELINGAN RESERVOIR USING USLE AND MUSLE METHODS

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Abstract

Tirtomarto reservoir or their people call it the Delingan reservoir because of its location in the village of Delingan, Karanganyar District, Karanganyar Regency, Central Java Province in Indonesia, it has an important role in meeting irrigation needs for agricultural land covering area of 1380 ha every year, but over time the Delingan reservoir is now visible. experienced a decrease in its water capacity and resulting in a decrease in water supply for agricultural land. This is due to the large value of land erosion that occurs. This study aims to calculate the value of land erosion that occurs in the catchment area of the Delingan reservoir which can later be handled so that sedimentation in the reservoir can be overcome and the water supply is maintained. Prediction of soil erosion in this study using the USLE (Universal Soil Loss Equation) and MUSLE (Modified Universal Soil Loss Equation) methods. The results of this study obtained the value of the erodibility factor of rain (R) from

2015-2019, the soil erodibility factor (K) of 0.04, the length and slope factor (LS) of 1.991134206, the factor of land cover plants and the factor of conservation measures. (CP) of 0.035456901. In the USLE method, the erosion value is 7605.891488 tons/year. Then the maximum flood discharge value (QP), surface runoff (QQ), and surface runoff (R) can be obtained so that the erosion value using the MUSLE method is 862.88 tons/year.

Keywords: erosion, sedimentation, USLE, MUSLE

1. INTRODUCTION

The Tirtomarto Reservoir, another name for the Delingan Reservoir is an important building for the preservation and continuity of its functions and benefits because for decades it has played an important role in meeting the needs of water supply for agricultural land covering area of 1380 ha. The reservoir which was built in 1920 and completed in 1923, namely during the Dutch East Indies government era, is now seen to have decreased in its water storage capacity due to sedimentation in the body of the reservoir (Muntiani dkk, 2019; Annisa, 2020). This problem cannot be denied because of the occurrence of erosion and sedimentation that occurs in the catchment area of the Delingan Reservoir so that the stream of sediment originating from upstream flows and settles in the body of the reservoir (Abdurrosyid, 2003). This is what underlies this research to analyze soil erosion and sedimentation that occurs in the catchment area of the Delingan Reservoir.

Based on the description of the background above to maintain the sustainability and continuity of the functions and benefits of the reservoir, it is necessary to conduct research and studies on land erosion and sedimentation, that is, it can be formulated how the rate of land erosion and the rate of sedimentation that occurs in the catchment area of the Delingan reservoir.

The expected objective of this research is to determine the rate of land erosion that occurs in the catchment area of the Delingan reservoir using the USLE (Universal Soil Loss Equation) method and the MUSLE (Modified Universal Soil Loss Equation) method.

The problem of this research is that this research was conducted in the Tirtomarto Reservoir area, Delingan Village, Karanganyar Regency, Central Java Province, Indonesia. The prediction of land erosion in the catchment area of the Delingan reservoir uses the USLE and MUSLE methods, this study is based on the area of the watershed in the Delingan reservoir obtained from the Bengawan Solo River Basin Center (BBWSBS), the rainfall value to be discussed in this study is based on BBWSBS secondary data, and soil erosion and sedimentation predictions observed in the reservoir are calculated from 2015 to 2019.

2. THEORETICAL BASIS

2.1. Reservoir

The most common understanding of a reservoir is a water reservoir on the ground surface when the rainy season arrives which the water can be utilized during the dry season. According to Indonesian government regulation number 37 of 2010, to store water during the rainy season so that it can be used to meet water needs and water resources when needed, as well as control the destructive power of water as referred to in article 22, article 34 and article 58 of the Law Law No. 17 of 2019 (Annisa, 2020) concerning water resources in Indonesia, it is necessary to form a reservoir that can hold water.

2.2. Erosion

2.2.1. Definition of Erosion

According to Kironoto and Yulistianto, 2000 (in Abdurrosyid, 2003) Erosion or subsidence of soil is a process of washing away the soil by pressures or the force of water (and wind), which takes place naturally or as a result of human actions. Therefore, the terms normal or geological erosion and accelerated erosion are known.

2.2.2. Erosion Rate Analysis

a. USLE (Universal Soil Loss Equation) Method

The formulation of the USLE method allows planning to predict the erosion rate of a particular land with a slope at a certain rain pattern and soil type as well as land management and use for crops or land conservation. The proposed USLE equation is as follows. Abdurrosyid (2003).

The proposed USLE equation is as follows. Suripin (2004) (in Abdurrosyid, 2003; Rohmaniah, 2016; Sunandar, 2017) .

$$Ea = R \times K \times LS \times CP \tag{1}$$

1) Erosivity of rain (R)

The amount of erosivity of rain is calculated by the equation:

$$R = \sum_{i=I}^{n} EI_{30} \quad (2)$$

$$EI_{30} = 6{,}119Pb^{1{,}211}.N^{-0{,}474}.Pmax^{0{,}526} \quad (3)$$

2) Soil Erodibility (K)

The soil erodibility factor is the erosion rate per rain erosion index (R) for soil obtained from a standard trial plot, that is, a test plot that is 72.6 ft (22.1 m) long and located on a 9% slope without plants. The K value (soil erodibility index) can be obtained from the following table.

Table 1. Soil Erodibility Factor (K) Based on Soil Type. (Suripin, 2004)

No	Land/Location	K (US units)	K (estimation metric) (USLE)
1	Latosol, Darmaga	0,02	0,04
2	Mediteran, Citaman	0,1	0,13
3	Mediteran, Ciputat	0,25	0,22
4	Mediteran, Punung	0,25	0,22
5	Grumosol, Jegu	0,24	0,25

(Source: Abdurrosyid, 2003)

3) Slope Length and Slope Factor (LS)

The length and slope factor of the slope can be determined based on the following formula:

$LS = (L/22)^z\ (0{,}006541S^2 + 0{,}0456S + 0{,}065)$ (4)

4) Land Cover Factors and Conservation Measures (CP)

Land cover factor values and conservation measures can be determined based on the following table.

Table 2. Land Cover Factors and Conservation Measures (CP)

No.	Land Use	**Value (*CP)***
1	Savana dan Prairie	0,01
2	Swamp	0,01
3	Shrubs/Srub	0,3
4	Mixed Dryland Agriculture	0,19
5	Dry Land Agriculture	0,28

6	Gardens	0,2
7	Mixed Garden Medium density	0,2
8	Production Forest Select	0,2
9	Undisturbed Forest	0,01
10	More Litter Natural Forest	0,001
11	Little Litter Natural Forest	0,005
12	Rice Field Irrigation	0,02
13	Non-specific dry land	0,7
14	Open Soil For Plants	1
15	Body of Water	0.001

(Source: Asdak, 2007 in Abdurrosyid, 2003))

b. MUSLE (Modified Universal Soil Loss Equation) Method

The MUSLE method is a modification of the USLE method. In this method the flow factor or surface runoff *(R_O)* is used, replacing the erosivity of the rain (EI) used in the USLE method. Suripin 2002 (in Fauzi, 2016, Krisnayanti 2018; Mekarsari, 2019; Adhiani, 2019) with the following equation. The proposed MUSLE equation is as follows, amount of eroded soil :

$$SY= a(Vq.Qq) \times K \times LS \times CP \quad (5)$$

Surface runoff is runoff that always flows through the soil surface (before and after reaching the canal). In determining the runoff factor, the data needed first are as follows.

1. Surface Flow (Qq)

The magnitude of the peak flow can be calculated using the rational method. Where this rational method is generally used to calculate flood discharge in watersheds that are not too broad with a limit of up to 50 km^2. The general rational formula by Hadisutanto 2011 (in Alie, 2015; Krisnayanti 2018; Mekarsari, 2019).

$$Q_q = 0.278 \times C \times I \times A \quad (6)$$

2. Surface Flow Volume (V_Q)

The value of the volume of surface runoff (V_Q) can be known after the rainfall height and watershed area in one sub-region are known first, then the value can be determined by the formula (Edriani, 2014; Fauzi, 2016) :

$$V_Q = \sum \text{rainfall} \times (\text{overflow water / max rain}) \times \text{Catchment Area} \quad (7)$$

3. Surface Runoff

After knowing the value of V_Q and Q_P, then the value of R_O (Dewi, 2012; Edriani, 2014; Fauzi, 2016) can be obtained using the following formula:

$$R = a \times (V_Q \times Q_P)^b \tag{8}$$

3. RESEARCH METHODS

3.1. Data collection

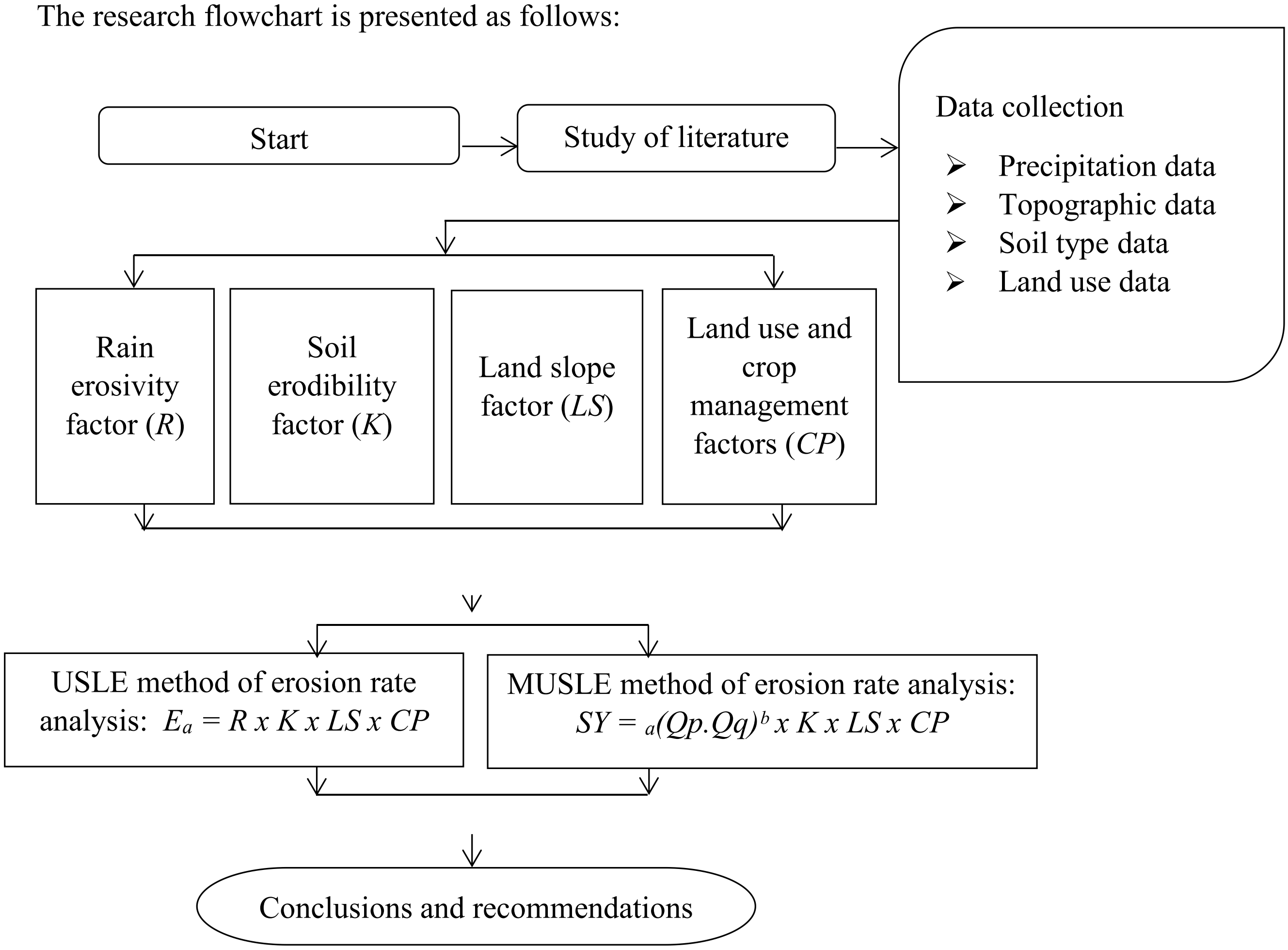
The data obtained for this research comes from:

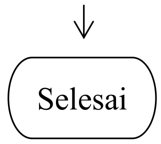
Table 3. Data collection

Jenis data	Sumber
Rainfall	BBWS Bengawan Solo
Soil Type	DLH Kabupaten Karanganyar
Land Use Map	BAPPEDA Kabupaten Karanganyar

3.2. Research of Flow Chart

The research flowchart is presented as follows:





4. RESULTS AND DISCUSSION

4.1. USLE (Universal Soil Lost Equation) Method

1. Rain Erosivity (R)

Rain Erosivity values from 2015-2019 are obtained from the following equation:

$$R = \sum_{i=1}^{n} EI_{30}$$

$$EI_{30} = 6{,}119 Pb^{1{,}211} . N^{-0{,}474} . Pmax^{0{,}526}$$

Table 4. Rain Erosivity Values for 2015-2019

Year	Rain erosivity
2015	2358,25
2016	4138,45
2017	1875,28
2018	1615,19
2019	1552,36

2. Soil Erodibility (K)

The step in finding soil erodibility (K) values requires soil type data or soil content on a soil type map as follows.

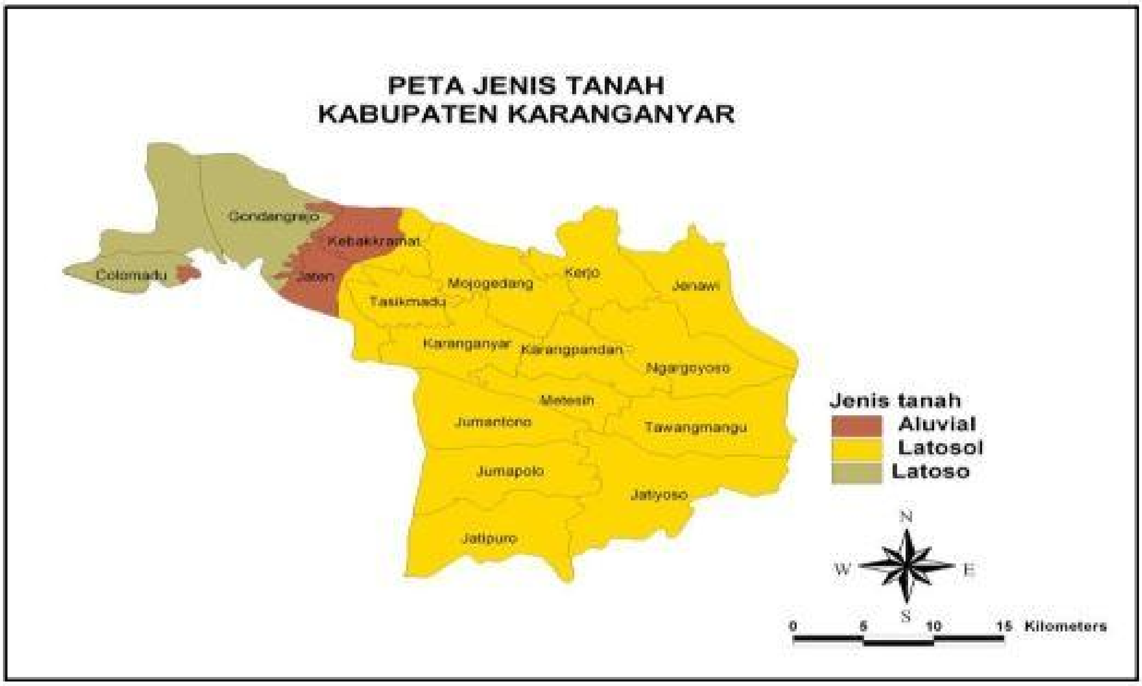


Figure 1. Soil Type Map

(Source: PWS Bengawan Solo, 2000)

Based on the soil map above (figure 1), it is known that the soil type is Latosol, then based on table 1 above the soil erodibility (K) is 0.04.

3. Slope Length and Slope Factor (LS)

Steps in determining the value of the length factor and slope (LS) are obtained by using the following equation (4):

$LS = (L/22)^z\ (0{,}006541S^2 + 0{,}0456S + 0{,}065)$

$LS = 1{,}991134206$ m

4. Land Cover Factors and Conservation Measures (CP)

Land cover factor values and conservation measures (CP) are obtained from the land cover map as follows.

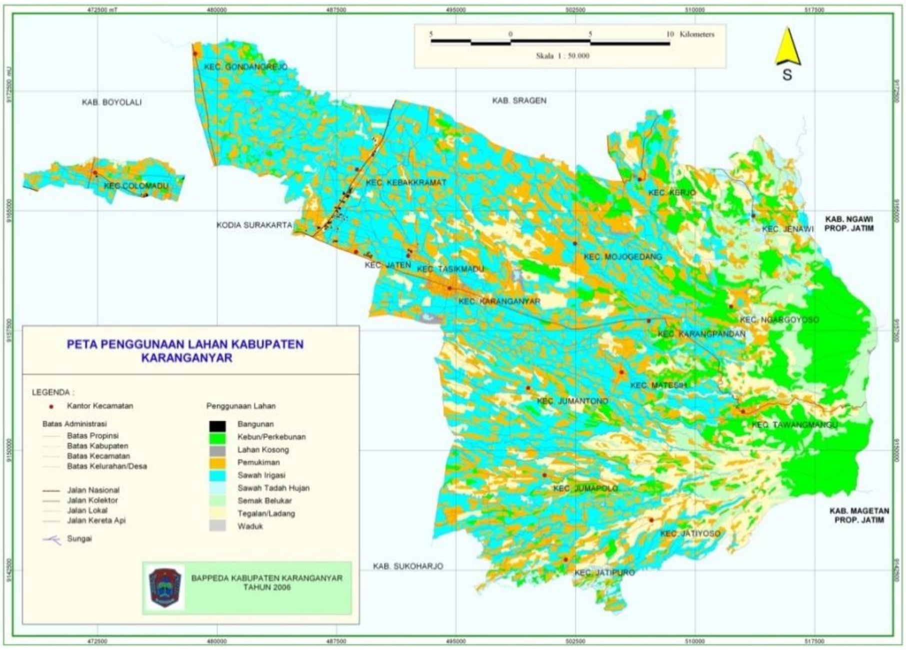


Figure 2. Slope Map (Source: PWS Bengawan Solo, 2000)

Based on the land cover map (figure 2), data is obtained which is then analyzed and the CP value is obtained as follows:

Table 5. Determining CP Value

No	Unit	CP	Area (km)	CP x Area
2	Rice fields	0,02	3,441842	0,068837
4	Plantation/Garden	0,20	0,430566	0,086113
5	Lake	0,001	0,182148	0,000182
6	Grasslands	0,01	0,446645	0,004466

$$CP = \sum Cp\ x\ Luas\ / \sum Luas$$

CP = 0,1596/ 4,501201

CP = 0,035457

5. Erosion rate using the USLE method

The results of the USLE method rate analysis can be seen in the following table:

Table 6. Analysis of the erosion rate of the USLE method

Year	R	K	LS	CP	E_a (tons/year)
2015	2358,25	0,04	1,991	0,0354569	7771,798969

2016	4138,45	0,04	1,991	0,0354569	13638,59551
2017	1875,28	0,04	1,991	0,0354569	6180,137246
2018	1615,19	0,04	1,991	0,0354569	5322,998201
2019	1552,36	0,04	1,991	0,0354569	5115,927514

4.2. The MUSLE (Modified Universal Soil Lost Equation) method

1. Peak flow (Qq)

The value of surface runoff can be seen in the following table:

Table 7. Peak flow value (Q_q)

Tahun	C	I	A (km²)	Qp (m³/s)
2015	0,226954795	21,24539232	11,67	15,64299
2016	0,226954795	27,20896471	11,67	20,033971
2017	0,226954795	15,28177343	11,67	11,251975
2018	0,226954795	20,87266614	11,67	15,368552
2019	0,226954795	16,58631506	11,67	12,21251

2. Surface flow volume (Vq)

The volume value of surface runoff can be seen in the following table:

Table 8. Value of surface runoff volume (Vq)

Tahun	Vq (m³)
2015	4828183
2016	8112218
2017	4889079
2018	3864069
2019	3874508

3. Surface runoff (R)

From the analysis of surface runoff and surface runoff volume, surface runoff can be calculated in the following table:

Table 9. Surface runoff (R)

Year	a	Vq	Qp	R
2015	11,8	4828183,132	15,64299	304523
2016	11,8	8112217,605	20,033971	467724
2017	11,8	4889079,136	11,251975	254998
2018	11,8	3864068,906	15,368552	266159
2019	11,8	3874508,221	12,21251	234366

4. Erosion rate using the MUSLE method

The results of the MUSLE method rate analysis can be seen in the following table:

Table 10. Analysis of the erosion rate of the MUSLE method

Year	R	K	LS	CP	Erosion (tons/year)
2015	304522,91	0,04	1,99113	0,0354569	859,97
2016	467724,07	0,04	1,99113	0,0354569	1320,84
2017	254998,29	0,04	1,99113	0,0354569	720,11
2018	266159,26	0,04	1,99113	0,0354569	751,63
2019	234365,70	0,04	1,99113	0,0354569	661,84

the average erosion of the MUSLE method was 862.878 tons/year.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

Based on the analysis that has been carried out regarding predictions of soil erosion that occurs in the catchment area of the Delingan reservoir using the USLE and MUSLE methods, several conclusions can be made as follows:

1. The annual average erosion rate in the catchment area of the Delingan Reservoir using the USLE Method is as follows:

Erosion value = 7605.891 tons/year.

2. The annual average erosion rate in the catchment area of the Delingan Reservoir using the MUSLE Method is as follows:

Erosion value = 862.878 tons/year.

5.2. Recommendation

Suggestions that can be given based on this research include:

1. Research on land erosion in the catchment area of the Delingan Reservoir, especially in the calculation of the USLE and MUSLE methods, uses maps more than using the existing formula, so in future research, if complete data is obtained, use the existing formula so that the results obtained can be more accurate.
2. To be more disciplined in analyzing and reading the data on the available maps, so that the appropriate results are obtained. Because the results obtained have a direct effect on how big or small the amount of erosion and sedimentation that occurs.

6. NOTATION

Ea = erosion that occurs (tons/ha/year)

R = rain erosivity

K = soil erodibility

LS = length and slope factor

CP = land cover factor and conservation measures

EI_{30} = Monthly rain erosion index (Kj/ha)

Pb = Monthly rainfall (cm)

N = Number of rainy days per month

$Pmax$ = Maximum daily rain (24 hours)

L = slope length (m)

S = slope steepness (%)

Z = a constant that depends on the steepness of the slope

SY = Yil sediment per rainfall event (ton)

R_O = surface runoff

C = vegetation cover factor

P = soil management factor/soil conservation measures

Q_q = peak flow (m3/s)

C = runoff coefficient

I = rain intensity (mm/hour)

A = catchment area (km2)

a = coefficient 11.80 (Williams, 1977)

V_Q = surface runoff volume (m3)

Q_P = peak flow (m3/s)

b = coefficient 0.56 (Williams, 1977)

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