Estimation of sediment yield based on correlation between potential land erosion using Universal Soil Loss Equation (USLE) and actual sediment load using Schaffernak Method in Situ Gintung Dam

W O N J Gabrielle*, D Sutjiningsih, E Anggraheni, and S Murniningsih
Departement of Civil Engineering, Faculty of Engineering, University of Indonesia, Kampus Baru UI Depok, 16424, Indonesia

E-mail: gbygab@gmail.com

Abstract. Sediment yield is eroded soil that transported from a place to a measurement point, for example in a reservoir. Sediment in the reservoir is a problem that can reduce the performance of the reservoir, so it needs to be assess regularly. One of many ways to assess is to calculate the potential of sediment that enters the reservoir. The research objective is to calculate the potential of sediment that enters the reservoir at Situ Gintung Dam using two methods, the Universal Soil Loss Equation (USLE) and Schaffernak methods. The USLE method calculate sediment that comes from land erosion of a watershed, but the potential land erosion that occurred is not necessarily create actual sediment load at the river bed so it needs to be correlated with the results of the actual sediment load. The actual sediment load can be calculated using Schaffernak method. The results of that obtain from each method will analysed to confirm the representativeness of the potential land erosion in Situ Gintung Dam. Percent of potential land erosion that transform into the sediment in the water body can be calculated by the value of Schaffernack method.

1. Introduction
Sediment yield is the quantity of sediment passing through a river cross section which is monitored per unit area drained upstream of that section (Church & Slaymaker, 1989). It is the product of all the results of the sediment production process and sediment transport in the watershed. Consequently, the prediction of basin sediment yield should take into consideration all different erosion and sediment transport processes[1-6].

The existence of sedimentation in the reservoir can be seen as the process by which the reservoirs accumulate sediments until they eventually become completely filled. Sediment in the reservoir can decrease the capacity of the reservoir so it needs to be monitored regularly.

There are two methods for calculating the potential yield of sediment that enter the reservoir, namely the USLE and Schaffernak methods. The Universal Soil Loss Equation (USLE) method is a model for estimating the erosion rate of a watershed proposed by Wischmeier and Smith. The Schaffernak method is used to calculate sediment transport in water bodies [7-11].

Both methods provide the same output as sedimentation rates. In the USLE method, the output obtained is the magnitude of the predicted results of the erosion of a watershed, whereas in the
Schaffernak method, the output obtained is the amount of sediment load in water bodies. The results of each method will then be analyzed to confirm the representativeness of the potential land erosion.

The research was conducted at Situ Gintung Dam located in East Ciputat District, South Tangerang City, Banten Province. The Situ Gintung Dam was built in 1933 during the Dutch Colonial period and was reconstructed in 2010 due to the catastrophic collapse of the dam in 2009. Based on data from the Balai Besar Wilayah Sungai (BBWS) Ciliwung Cisadane in Kompas article on March 27th 2009, the Gintung Dam experienced silting, marked by the original area of Situ Gintung Dam was 31 hectares, and now is only 21.4 hectares.

2. Materials and Methods

2.1. Study Area

Because the research objectives are to estimate the rate of erosion and sediment load that enter Situ Gintung Dam, the study area used is limited to sub-watersheds which outlet are the inlet of Situ Gintung Dam. There are 4 sub-watersheds in Situ Gintung Watershed, and 3 of them and its outlet will be the study area. Situ Gintung and the 3 sub-watershed that will be the study area can be seen in Figure 1. For the USLE method, the study was conducted at the sub-watershed 1, 2, and 3 and for the Schaffernak method, the study was conducted at Situ Gintung Dam inlets. The 3 Situ Gintung Dam inlets can be seen in Figure 2.

![Figure 1. Situ Gintung Dam and the 3 sub-watershed](image1.png)

![Figure 2. Situ Gintung Dam Inlets](image2.png)

2.2. Description of the Model

2.2.1. USLE Method

The results of surface erosion from a watershed can be estimated based on the estimated erosion rate in the watershed (Sutjiningsih, Soeryantono, Widayat, & Garniwan, 1997). One of many methods for estimating the amount of surface erosion is the Universal Soil Loss Equation (USLE) proposed by Wischmeier and Smith ([11] with the formula in Equation (1). USLE was developed as an equation of the main factors controlling soil erosion, namely climate, soil characteristics, topography and land cover management (Gitas, Douros, Minakou, Silleos, & Karydas, 2009). The USLE provides the most frequently used model for predicting soil loss in the world (Kinnel, 2017). The term “universal” indicates that the equation can be used to estimate the magnitude of the rate of erosion in a variety of different land use and climate conditions (Asdak, 2007).

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot P \]  

(1)

Where:

- \( A \) : erosion rate of a watershed (tons/ha/year)
- \( R \) : rain erosivity index
- \( K \) : soil erodibility index
- \( L \) : length index
- \( S \) : slope length index
- \( C \) : cover and management factor
- \( P \) : support practice factor
2.2.2. Schaffernak Method
The Schaffernak method estimates the amount of annual sediment in a river cross section (Sutjiningsih, Soeryantono, Widayat, & Garniwan, 1997). The Schaffernak method shows the relationship between frequency, water discharge, and sediment transport (Garde & Raju, 2000). The results of this method are the sediment duration curve which is derived based on a combination of the discharge duration curve and the sediment rating curve (Sutjiningsih, Soeryantono, & Anggraheni, 2015). Sediment yield is obtained as the shaded area in Figure 3.

![Figure 3. Estimation of Sediment Load Rate by the Schaffernak Method](image)

2.3. Research Procedure
Research procedure is presented in Figure 4. The parameters used in the USLE method are rain erosivity index (R), soil erodibility index (K), length and slope index (LS), crop management index (C), and soil conservation index (P). In Schaffernak method, the discharge duration curve is obtained from the rain data series converted to a flow data series through the rain fall-runoff relationship model using WinTR-20, while the sediment rating curve is obtained from total suspended solid (TSS) data and discharge from the conversion of the rainfall data using WinTR-20. WinTR-20 is a single event watershed scale runoff and routing model. It computes direct runoff and develops hydrographs resulting from any synthetic or natural rainstorm (WinTR-20 User Documentation).

3. Results and Discussion
3.1. USLE Method
After the parameters in the USLE equation have been determined, the magnitude of the erosion rate entering the Gintung Dam can be determined by multiplying the parameters in the USLE equation. The parameters in the USLE equation consist of R values, K values, LS values, and CP values. The R value for sub-watershed 1, 2, and 3 can be seen in Table 1. Equation used to calculate the value of R is the Bols equation (1981). The K value is based on the type of soil in each sub-watershed, where the soil type in sub-watershed 1, 2, and 3 is Typic Dystrudepts which has a K value of 0.21, obtained from Departemen Pertanian (2004). The LS value for sub-watershed 1 is 0.0164, sub-watershed 2 is 0.0165, and sub-watershed 3 is 0.0165, obtained from the calculation of LS value where the LS equation used is the Wischmeier Equation (1971). The CP value in sub-watershed 1 is 0.54, sub-watershed 2 is 0.71, and sub-watershed 3 is 0.69, where the calculation is based on the land use map in the watershed and CP value obtained from Asdak (2007). By multiplying these parameters, the estimated erosion rate results for sub-watershed 1 is 3.87 tons/ha/year or 1229.36 tons/year, sub-watershed 2 is 5.11 tons/ha/year or 587.21 tons/year, and sub-watershed 3 is 4.95 tons/ha/year or 76.73 tons/year.
Table 1. Rain Erosivity Index

| Month  | R value |
|--------|---------|
| January| 222.19  |
| February| 224.60 |
| March  | 128.14  |
| April  | 196.11  |
| May    | 185.95  |
| June   | 143.44  |
| July   | 138.09  |
| August | 75.88   |
| September| 124.98 |
| October| 162.04  |
| November| 238.98 |
| December| 236.05 |

Figure 4. Research Flow Chart

3.2. Schaffernak Method
In the Schaffernak method, the end result is a sediment load that can be obtained by calculating the area under the sediment duration curve. The sediment duration curve is derived based on a combination of the discharge duration curve and the sediment rating curve. The area between the curve duration of the sediment duration curve and the time axis illustrates the amount of sediment transported by the river during the year. The area is calculated using the AutoCAD application by hatching the area under the curve and calculating the properties of the hatch's area. The results of sediment load in river bodies for sub-watershed 1 is 1.11 tons/ha/year or 352.52 tons/year, sub-watershed 2 is 2.09 tons/ha/year or 240.45 tons/year, and sub-watershed 3 is equal to 0.27 tons/ha/year or 4.23 tons/year.

3.3. Analysis Representation of Potential Land Erosion
In the USLE method, the largest erosion rate (in tons/ha/year) is in sub-watershed 2 with a value of 5.11 tons/ha/year, then followed by sub-watershed 3 with a value of 4.95 tons/ha/year, and the smallest is sub-watershed 1 with a value of 3.87 tons/ha/year. Based on the results of data processing, the R value,
the K value, and the LS value for each sub-watershed are almost the same. The most differentiating factor of each sub-watershed is the CP value, so it can be said that in the USLE method, the difference rate of erosion in each sub-watershed is influenced by land use factors that exist in each sub-watershed.

Based on the results of the USLE method, the smallest erosion rate is in sub-watershed 1, which is 3.87 tons/ha/year. This is proportional to the CP value where sub-watershed 1 is also the sub-watershed which has the smallest CP value (0.54). In addition, in sub-watershed 1, there is an airstrip which is quite extensive and is dominated by grazing land. The presence of grass or plants that cover the soil on the land can prevent erosion.

In the Schaffernak method, the largest sediment load (in tons/ha/year) is sub-watershed 2 with a value of 2.09 tons/ha/year, then followed by sub-watershed 1 with a value of 1.11 tons/ha/year, and sub-watershed 3 with the value of 0.27 tons/ha/year. Overall, the results from Schaffernak method is still not represent the actual sediment load in the field. There are several possible causes, one of which is the total suspended solid (TSS) data used is data obtained from water quality data, where TSS data that should be used is from direct sediment sampling in the field (Due to Covid-19 pandemic, we can’t do direct sediment sampling in the field). In addition, the flow rate used to create a discharge duration curve is obtained from the conversion of the rain data series into a series of flow data through the WinTR-20 application and not the actual discharge value in the field.

The results of erosion rates by the USLE method and sediment loads by the Schaffernak method are then analyzed to see the representation of potential land erosion. The results of the two methods for each sub-watershed are presented in Table 2. Based on Table 2, the amount obtained from the USLE method results is greater than the results from the Schaffernak method. This indicates that not 100% of land erosion results succeed in becoming a sediment load in water bodies.

| Sub-Watershed | USLE tons/ha/year | Schaffernak tons/ha/year | Representation of Potential Land Erosion |
|---------------|-------------------|--------------------------|------------------------------------------|
| Sub-Watershed 1 | 3.87              | 1.11                     | 28.68%                                   |
| Sub-Watershed 2 | 5.11              | 2.09                     | 40.95%                                   |
| Sub-Watershed 3 | 4.95              | 0.27                     | 5.51%                                    |

On the right of Table 2, there is a percentage representation of the potential of land erosion, where the value shows how much the predicted erosion rate has succeeded in becoming a sediment load in a body of water. The percentage results of representation of potential land erosion in each sub-watershed are different. This is due to differences in the characteristics of the watershed and its drainage in each sub-watershed. The results of the USLE and Schaffernak methods also provide the possibility of developing a regression equation that links the results of erosion rates in watersheds with sediment loads in water bodies. However, this requires quite a large series of erosion rate and sediment load data to be analyzed for regression. The results of the regression analysis can also be used to see the potential magnitude of erosion that becomes a sediment load in a water bodies in the future if there are changes in the characteristics of the watershed.

4. Conclusion

Based on the results of research and discussion discussed previously, some conclusions are drawn as follows: the predicted results of watershed erosion rates using the USLE method are sub-watershed 1 with a value of 3.87/ha/year or 1229.36 tons/year, sub-watershed 2 with a value of 5.11 tons/ ha/year or 587.21 tons/year, and sub-watershed 3 with a value of 4.95 tons/ha/year or 76.73 tons/year. Based on the results of the analysis in the USLE method, Sub-watershed 1 has the smallest erosion rate. It is because in Sub-watershed 1 there is a large amount of plots of land when compared to Sub-watersheds...
2 and 3. From these results it can be concluded that the land covered by plants can prevent erosion that occurs in the watershed.

Then, the results of sediment load in water bodies using the Schaffernak method are sub-watershed 1 with a value of 1.11 tons/ha/year or 352.52 tons/year, sub-watershed 2 with a value of 2.09 tons/ha/year or 240.45 tons/year, and sub-watershed 3 with a value of 0.27 tons/ha/year or 4.23 tons/year. However, the results from Schaffernak still do not represent the actual value, because the TSS data used are data obtained from water quality data, where TSS data should be used as data from direct sediment sampling in the field. In addition, the flow rate used to create a discharge duration curve is the conversion of the rain data series to the flow data series through the WinTR-20 application and not the actual discharge value in the field.

Furthermore, percentage analysis of the representation of potential land erosion obtained in sub-watershed 1 is 28.68%, sub-watershed 2 is 40.95%, and sub-watershed 3 is 5.51%. The results of the percentage representation of potential land erosion in each sub-watershed indicate that not 100% of land erosion results have succeeded in becoming sediment load in water bodies. In addition, the results obtained for each sub-watershed are different due to differences in the characteristics of the watershed and its drainage in each sub-watershed. The results of the USLE and Schaffernak methods also provide the possibility of developing a regression equation that links the results of erosion rates in watersheds with sediment loads in water bodies. The results of the regression analysis can be used to see the potential magnitude of erosion that becomes a load in a body of water in the future if there are changes in the characteristics of the watershed.

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