Best management practices for erosion and sedimentation control of The Sermo Watershed

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Abstract. Erosion and sedimentation problems caused by human activities disturbed the primary conditions of the watershed. This situation was also influenced by significant hydrometeorological shifts and high rainfall, which increased soil erosion. These inclement watershed conditions resulted in high sedimentation rates and caused severe problems for the quality and quantity of water in the reservoir. This study aims to solve the Sermo watershed problems by calculating the value of erosion and sedimentation, then providing a solution to deal with these problems in the form of Best Management Practices (BMP). This research used a USLE method to calculate the erosion and sedimentation rate. The calculation results showed that 40.86% of Sermo Reservoir within 809.12 hectares was classified as a high level of erosion. Further recommendations for overcoming this condition were made by referring to BMP for erosion and sediment control, including structures and soil water conservation. Further recommendations to address this condition were made regarding BMP for controlling water, maintaining soil stability, controlling sedimentation, and managing and maintaining optimal watersheds.

Keywords: erosion, dam, sedimentation, best management practices

1. Introduction
A watershed is a spatial area that explicitly contains various interacting physical, ecological, and social attributes [1]. This area is bounded by ridges or mountains and receives rainwater that will flow at one outlet. Within the watershed, there are regulatory functions (e.g., climate regulation, flood regulation, and water pollution) [2]. With this function, a watershed is very important for the survival of mankind. Although watersheds have provided many benefits to human life, they are still exploited by humans for their interests. The bad impact of this overexploitation is a decrease in the quality of the watershed conditions. In addition, the acceleration of land-use change, water consumption, and climate change also accelerate the decline in the quality of the watershed. [1]
Damaged watersheds can result in a decrease in the amount of water stored in the soil. Because the water will become a surface runoff and will directly enter the river. The International Soil Science Society termed soil as "limited and irreplaceable resource." Without this, the region of the earth's surface and atmosphere where living organisms exist would crack, with adverse effects on humanity. Soil keeps carbon dioxide (CO2) and other greenhouse gases in the soil's organic matter. The effect is that the quantity of river discharge will fluctuate significantly between the rainy and dry seasons. In addition, the damaged watershed conditions are directly proportional to land erosion and sedimentation rates. The rate of erosion can lead to sedimentation, affecting river capacity, reservoir storage capacity, and river water quality. Conditions like this make an area prone to floods and landslides in the rainy season and drought in the dry season [3]. The further impact of the damaged watershed conditions will also affect the economic sector.

Soil erosion by water and wind leads to undesirable soil effects, resulting in the loss of fertile topsoil and caused land degradation. To overcome this condition, Best Management Practices are needed to be implemented to control the erosion and amend the environmental quality [4]. Controlling erosion is all about decreasing the power of the water or wind and protecting the soil from it. The power is decreased by applying best management practices that influence the soil, surface cover, watershed size, slope, or slope length, or decrease the volume or velocity of runoff. Decreasing the power is not always possible, but protecting the soil from the power of water and wind by covering it can always be done. Protecting by applying mulch or other protections is usually the most practical method of preventing erosion[5].

The type of erosion control BMPs used is determined by the type of erosion that is occurring. The basic principles apply to protect the soil and/or reduce the flowing water's power (velocity and depth). To control wind erosion, controlling the velocity of the wind is done by using windbreaks and adsorbing or deflecting the power. This is not always practical, but it can protect the soil from the power of the wind in the same way as with the water – by covering it[5]. Further recommendations in implementing BMP were made by referring to Best Management Practices for erosion and sediment control, including structures and soil water conservation[6].

Table 1. Previous studies related to sediment transport

| No | Title                                                                 | Author's            | Year | Output                                                                 |
|----|-----------------------------------------------------------------------|---------------------|------|------------------------------------------------------------------------|
| 1  | Estimation of Sedimentation Volume Within Sermo Reservoir Using RUSLE, Bathymetry, and Sediment Transport Methods | Annisa Wulandari, Bambang Kun, Cahyono | 2020 | The results of the estimated sedimentation volume of the Sermo. Reservoir using the RUSLE method, bathymetry, and sediment transport. |
| 2  | Best Management Practices Effectiveness To Reduce Sediment Transport To Morro Ba | Michael James, Randall | 2012 | Chorro Creek Subwatershed BMP Effectiveness Ranking.                   |

Previous studies (table 1) carried out in the Sermo watershed are to calculate the amount of sediment in the Sermo Reservoir using various methods, including RUSLE, bathymetry, sediment transport. In this study, specific handling of the sedimentation problem in the Sermo watershed has not been added. However, suppose refer to studies conducted other than in the Sermo watershed. In that case, there are already BMPs
to deal with sediment problems in a watershed, and their effectiveness is calculated. Our research aims to calculate the value of erosion and sedimentation that occurred in the Sermo watershed and then provide a solution in the form of BMP.

With a scientific approach to estimate sedimentation, it is useful to get a real number of sedimentation hazards in a watershed [8] and know how to solve them. This research aims specifically to help solve sediment problems in the Sermo watershed through a scientific approach coupled with the application of BMP.

2. Material and Methods

2.1. Sermo Watershed characteristics

The object of this research is the Sermo Watershed, which is located in the Kulonprogo district. In terms of location, the Sermo Watershed is included in the Progo-Opak-Seran River Basin and covers an area of 21.23 km². This watershed has four rivers, including Ngrancah River, Lurung River, Bengkok River, Gelo River. The characteristic of this watershed is that the subsurface material is impermeable with moderate vegetation with high potential for runoff, high clay content, and low permeability. Within the Sermo DAS itself, there is the Sermo Dam, which has a storage capacity of 25.000.000 m³.

The data needed in this study include rainfall data for 2011-2020, topographical data of the Sermo watershed, and satellite imagery of the Sermo watershed. These data will later be processed to produce erosion rates and sedimentation rates. The calculation itself uses ArcGIS 10.4 software. In carrying out erosion hazard studies, guidelines are used to determine them. The reference can be seen in table 2 and table 3. This aims to get the rate of erosion and map it directly.
2.2. Rain Erosivity
The influence of climate on erosion is direct through the kinetic energy of rainwater, especially the intensity and diameter of raindrops. In intensive rain and lasts for a short time, the erosion is usually greater than rain with a smaller intensity with a longer rainfall. The amount of rainfall, intensity, and distribution of rain determine the strength of the rain dispersion on the soil, the amount and strength of runoff, and the level of erosion damage caused. Several equations of rainfall intensity have been developed by experts and are often used, depending on the availability of data and the type of rainfall measuring instrument. The EI30 calculation is calculated for each rain event using the following equation: developed by Bols (1978), which is a technical collaboration between the Bogor Soil Research Institute and the Belgian Government[7]:

\[
EI30 = 6,119 \times (RAIN)^{1.21} \times (DAYS)^{-0.47} \times (MAXP)^{0.53}
\]  

(1)

where:
- EI = Monthly rain erosion index
- RAIN = Monthly Average Rainfall (cm)
- DAYS = Average number of rainy days per month
- MAXP = Maximum rainfall in one month (cm)

2.3. Slope length factor (L) and slope (S)
Topographic index factors L and S represent the effect of slope length and slope on the amount of erosion. The length of the slope refers to the runoff of surface water, i.e., the location where erosion takes place and the possibility of sediment deposition[7]. The length and slope of the slope (L and S) are integrated into the LS factor, calculated by the formula:
LS = \sqrt{\frac{L}{22.13}} (0.065 + 0.0453 S + 0.0065 S^2) \quad (2)

Where:
L = Length of slope (m)
S = Slope (%)

While Moore and Burch (1986) have developed an equation to determine the value of LS by utilizing Geographic Information System (GIS).

| Slope Class      | Slope | LS Value |
|------------------|-------|----------|
| Flat             | 0-8   | 0.4      |
| Ramps            | 8-15  | 1.4      |
| Rather Steep     | 15-25 | 3.1      |
| Steep            | 25-40 | 6.8      |
| Very Steep       | >40   | 9.5      |

2.4. USLE Method

To estimate the amount of erosion that occurs is determined by the intensity of rain and the form of land management activities by humans, in addition to topographic factors and soil properties. Estimation of the amount of erosion on land can be used for land use planning and appropriate soil conservation measures so that there is no damage to the soil so that the land can be used productively and sustainably. Erosion estimates are also used to assess whether a program of soil conservation measures has succeeded in reducing erosion of a watershed. The erosion estimation method is a tool to determine the amount of erosion that will occur so that decisions can be made appropriately in planning soil conservation in a land use. Of the several existing methods for estimating the magnitude of surface erosion, the USLE method developed by Wischmeier and Smith (1978) is the most used. Another way to estimate the amount of erosion is to use data on sediment load, soil density, and the magnitude of the sediment delivery ratio[7]. The USLE equation developed by Wischmeier and Smith (1978):

\[ A = R \cdot K \cdot LS \cdot C \cdot P \quad (3) \]

where:
A = Amount of soil eroded (tons/ha/year)
R = Rainfall factor/rainfall erosivity
K = Soil erodibility factor
LS = Length and slope factor
C = Factors of ground cover vegetation and plant management
P = Factors of special soil conservation measures
Table 3. Erosion hazard classification

| Erosion Hazard Class | Erosion Hazard Class Land of the Lost, A, in (ton / ha / year) | Explanation       |
|----------------------|---------------------------------------------------------------|-------------------|
| I                    | <15                                                            | Very light        |
| II                   | 15-60                                                          | Light             |
| III                  | 60-180                                                         | Moderate          |
| IV                   | 180-480                                                        | Heavy             |
| V                    | >480                                                           | Very Heavy        |

2.5. Sediment delivery ratio (SDR)
SDR (Sediment Delivery Ratio) is the ratio of the amount of sediment transported into the water body/river with the amount of erosion in the upstream watershed. If the SDR value is close to one, it means that all soil carried by erosion enters the river. On the contrary, if the SDR value is close to zero, then the erosion rate in the watershed is shallow and indicates that the watershed is in a good category. Estimating the amount of sediment yield by calculating the SDR value of a catchment area is determined based on the analysis results of the erosion level. This method is commonly used when it is not possible to measure sediment directly in the field in a watershed. Calculating the magnitude of the SDR coefficient in each sub-das is based on the empirical equation (Wischmeier and Smith, 1978). Sediment Delivery Ratio can be formulated by[7]:

$$\text{SDR} = 0.41 A^{-0.3}$$

Where:
SDR  =  Sediment Delivery Ratio
A  =  Watershed area (km$^2$)

3. Results and Discussions

3.1. Polygon Thiessen
Thiessen's Polygon method is one of the most popular methods among practitioners of hydrology in calculating regional average rainfall[11]. The first step in carrying out this study is to work on the planned flood discharge with the output of the rain Polygon Thiessen map in the Sermo watershed. Rain data was obtained from rain station data around the study location. From the results of the analysis that has been carried out, it is found that the maximum daily rainfall in the Sermo watershed ranges from 100-200 mm with the distribution as shown in Figure 3. With this rainfall, it is included in the category of rain with moderate intensity.

As seen in Figure 3, the Sermo watershed influences two rain gauges (Plaosan Rain Gauge and Borrow Area Rain Gauge). Plaosan rain gauge and Borrow Area rain gauge percentages were 60.34% and 39.66%, respectively.
3.2. Erosion Rate

In the USLE method, the estimated magnitude of erosion is per year (annual). Accordingly, the average value of the R factor is calculated from the annual rainfall data as much as possible [10]. The rate of erosion, in brief, is the amount of erosion that occurs in an area within a certain period. In this study, the erosion rate was calculated using the USLE method. By using the results of the erosion prediction, which is the magnitude of the erosion threat generated by potential erosion on each land use, the total erosion that has occurred can be calculated. Total erosion is the accumulation of the amount of potential erosion multiplied by the area of each unit of land. Furthermore, the results of the evaluation of erosion threats and erosion measurements can be mapped.

Before analyzing the rate of erosion, the parameters that form erosion must first be determined, after the parameters are in place, the calculation of the rate of erosion can be carried out. The data used to analyze erosion rate are:

3.2.1. Land use

The information from this land use map is used to determine the soil cover factor, C coefficient, and mechanical erosion control factor. The data is the condition of the plan from the RTL-RLKT. It must be matched with field data obtained from field observations and interviews with residents to obtain existing data. The field data required include plant species composition, cropping patterns, planting calendar, conservation techniques, land status and percentage of land cover by plants.

As shown in Figure 4, Dryland Farming Mixed with Shrubs is the most dominant type of land use with a percentage of 67.57%. Then, dryland farming, water body, and settlement percentages are 22.91%, 32.20%, 0.19%, and 0.04%, respectively.

3.2.2. Soil Type

This soil map is used to obtain information about the soil type, which is then used to obtain the soil erodibility factor (K). As seen in figure 5, there are two types of soil in the Sermo watershed, namely Mediterranean soils, Grumusol, Regosol and Lithosol of 72.07% and Chocolate Latosol of 35.13%.
3.2.3. Slopes
Information about the slope and length of the slope in the Sermo watershed can be obtained from the slopes map. So, the index value of the slope length factor, LS, is obtained. Based on the analysis results (figure 6), the Sermo watershed generally has a very steep slope. More than half of the land area is in slope class IV (Steep) at 37.51% and slope class V (Very Steep) at 31.99%, where the slope factor values are 6.80 and 9.50.

3.2.4. Erosion Hazard Map
Based on the analysis results, the erosion hazard level in the Sermo watershed is quite severe. Class IV of 40.86% indicates a severe level of erosion hazard, and class V of 39.23%, which indicates a very severe erosion hazard. The others are divided into classes I, II, and III, namely 6.01%, 17.77%, and 3.33%. Meanwhile, when viewed from the average erosion of 199.587 tons/ha/year, the erosion hazard level in the Sermo watershed is classified as class IV, which indicates a heavy level. The result of this method can be seen in Figure 7.

The result is that the rate of erosion in the Sermo watershed is 199,587 tons/ha/year. With these results under table 3, the level of erosion hazard in the Sermo watershed is burdensome. The rate of erosion shows that almost 39.23% area in Sermo Watershed is the most dangerous because the total erosion is the highest.

3.2.5. Sedimentation Rate
The sedimentation rate is the amount of sediment accumulated in a catchment area or river basin within a certain period. The amount of erosion rate is directly proportional to sedimentation because land erosion will gather and form sediment. Sedimentation affects the useful life of the reservoir in the Sermo watershed, more sedimentation in the Sermo reservoir will reduce the useful life of the Sermo reservoir. The sedimentation results from the ArcGIS analysis show that area sub watershed 8 (in Figure 8) experienced the greatest sedimentation.
3.2.6. Erosion Potential Analysis
The exploration of erosion potential in the sub watershed land shows that the larger the area in the upstream part, the greater the sediment potential. The most significant sediment potential comes from sub watershed 1, which is 30,029.678 tons/year. Meanwhile, the smallest sediment potential comes from sub watershed 8, which is 4,269.892 tons/year.

The SDR value for the Sermo watershed for current conditions is:

$$\text{SDR value} = \frac{5912.600}{11} \div 83207.886 \times 100\% = \frac{537509.1}{83207.886} \times 100\% = 12.09\%$$

It means that 12.09% of the surface erosion that occurs (the result of the USLE formula) will enter the Sermo reservoir, while the remaining 87.9% will be left on the ground surface.

3.3. BMP’s Concepts
On the BMP’s Concepts, erosion and sedimentation control (ESC) uses practices and procedures to minimize erosion and settle out sediment before surface water leaves the work site. There are six principles in BMP-ESC[5]. At first, knowing the characteristics of the watershed is the most important, such as land use, rainfall, land slopes, the type of soil. In general, wooded areas will produce runoff slowly but for a longer time. Urban areas will quickly produce larger amounts of runoff for a given rainfall. Anticipating flow rates is critical to good water management. Moreover, based on the analysis results, it is known that there are two types of soil in the Sermo watershed, namely Mediterranean soils, Grumusol, Regosol, and Lithosol of 72.07% and Chocolate Latosol of 35.13%.

The second thing that must be considered in implementing BMP is to keep the disturbed area small. Land clearing is carried out only in areas that can be managed[5]. The smaller the bare land area exposed to rainfall and runoff so that less erosion will occur. It is next, controlling the water. The key to ESC is to keep the depth (volume) and velocity of water as low as possible. Then, the water flow must be diverted from the exposed soil. This can be done by making temporary ditches and hillsides diversions to divert water away from exposed soil so that water does not erode the soil surface.

The next principle is to maintain the stability of the soil[5]. The soil will be more stable if it has a cover such as grass or mulch. It will protect the soil from raindrop impact and promote the infiltration of runoff.
into the soil. Moreover, this will decrease the volume of water that runs off the site and slow down sheet runoff.

Subsequently, sedimentation control will be the last line defense, but it should be the first implementing BMP to make up almost all of the sediment caught here. At last, Watersheds must be adequately managed. It relates to inspection and maintenance[5]. Watersheds must be appropriately managed. It relates to inspection and maintenance. The watershed must be monitored regularly, making problems reports and follow-up plans. Then, it will solve existing problems quickly before the problems become more complicated and need extra effort to solve.

3.3.1. Structure

A check dam is a berm constructed across a drainage swale or ditch that reduces runoff velocity, allowing sediment to settle out behind the dam. Check dams are very effective in stopping the upstream head-cut movement of gully erosion. It does not prevent rill erosion in the bottom of a ditch. Channel linings are the best practice for preventing erosion in concentrated flow channels [5].

![Figure 9. The location of check dam planning map](image)

The following is an example of a check dam design that will be schematized at sub-watershed outlets 2 and 3 (as seen in figure 9). By designing a check dam on the river with a height of 7m, the dead storage volume can be estimated at approximately 183 m$^3$, and control volume storage = 307 m$^3$, so that the total capacity is 490 m$^3$. The average erosion rate in sub-watersheds 2 and 3 is 3 mm. With such a significant erosion rate, dredging is necessary every 2-3 months. This indicates that the construction of check dams without any treatment on the watershed will result in ineffective management in terms of energy and costs.

As previously explained, the role of check dams as last line defense is very important because check dams will capture almost all of the sediment load (suspended load and bed load). If the check dam reservoir is full of sediment, then the check dam is no longer functioning. The flow will still carry the sediment load to the reservoir. Especially during heavy rains that cause flooding, the ownership speed will be sufficient to drain large sediment loads such as bed loads. This situation, if left unchecked, will result in a continued reduction in the useful life of the reservoir. Therefore, comprehensive management is needed, such as the implementation of BMP. BMP is a wise practice that subsides and moderates the erosion problems[6].
3.3.2. Soil and Water Conservation Method
Soil conservation is how to keep the soil from being dispersed and regulate the strength of motion and the amount of surface runoff to prevent soil transport (erosion) [6]. Based on this, three things can be done for soil conservation actions, including:
- Cover the soil with plants to protect it from the damaging power of falling raindrops.
- Improve and maintain the condition of the soil.
- Regulate surface runoff to flow at a non-destructive rate and increase the water that infiltrates into the soil. Some methods of soil and water conservation that can be done:

3.3.2.1. Vegetative method
The vegetative method uses plants to reduce the impact of falling raindrops, reducing the amount and speed of runoff [7]. The following is the impact of the vegetation cover on erosion:
- Protects the ground surface from the impact of rainwater (reducing terminal velocity and reducing the diameter of rainwater)
- Decrease the speed and volume of running water
- Holds soil particles in place through the root system
- Maintaining the stability of the soil's capacity to absorb water.

3.3.2.2. Mechanic method
Mechanical conservation is how to physically treat the soil by holding, accommodating, and controlling eroded soil using retaining structures [7]. This is intended to reduce runoff and erosion and increase the usability of the land. There are several reasons to apply mechanical soil conservation;
- The flow of debris originating from the upstream area will threaten essential buildings in the downstream area.
- Reclamation in upstream areas is considered necessary for people's lives in the area.

3.3.2.3. Chemical method
Chemical methods in soil and water conservation are the use of chemicals in the form of synthetic compounds or in the form of natural materials that have been processed in relatively small quantities to increase the stability of soil aggregates and prevent erosion. Stable soil structure is one factor that has a positive effect on reducing soil erosion sensitivity and plant growth. Soil organic matter plays an important role in the formation of a stable soil structure as well as a reservoir of nutrients, improving soil structure, soil drainage, soil air circulation (aeration), soil cation exchange capacity, soil buffer capacity, soil water holding capacity, and is a source of energy for micro-organisms. Usually, the soil after being processed and cleaned of vegetation cover, the soil organic matter will rapidly decrease, so that the sensitivity of the soil to erosion will quickly increase, and soil productivity can quickly decrease[7].

3.3.2.4. The combination between vegetative and mechanic
The most effective erosion prevention technique is a combination of vegetative and mechanical means. The vegetative method emphasizes erosion prevention activities by planting vegetation. Meanwhile, mechanical means through the manufacture of buildings prevent erosion[7]. To restore the land quality that has been eroded, land rehabilitation and soil conservation are needed by:
- Increases soil surface stability and resistance to erosion and reduces soil mass movement.
- Reduce the strength of the erosion flow by reducing the flow velocity and discharge.
- Increase the infiltration capacity of land and increase its absorption capacity.
Actions to restore the land quality of a watershed/sub-watershed can be carried out using bio engineering, namely long-term action in the form of planting cover crops so that land cover density is obtained, preventing denudation, and regulating land use.

4. Conclusion

The Sermo watershed has an average rainfall of 100-200 mm and a very steep slope. With these characteristics, the Sermo watershed is prone to land erosion. The erosion rate in the Sermo watershed, which is calculated using the USLE method, produces an average erosion rate of 199,587 tons/ha/year, and this value is classified as class IV with a severe hazard level. The resulting erosion will become sediment that enters the Sermo Reservoir by 12.09%, and another 87.9% will be left on the ground surface. The handling of the problem of erosion and sedimentation uses the BMP concept. The BMP concept uses practices and procedures to minimize erosion and deposit sediment before surface water leaves the work site. In the BMP Concept, erosion and sedimentation control (ESC) uses practices and procedures to minimize erosion and deposit sediment before surface water leaves the job site. BMP itself has six principal points: knowing the watershed's characteristics, minimizing disturbed areas, controlling water, maintaining soil stability, controlling sedimentation, and managing and maintaining optimal watersheds.

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